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GENERAL ELECTRIC REVIEW

VOL. XXVIII, No. 8

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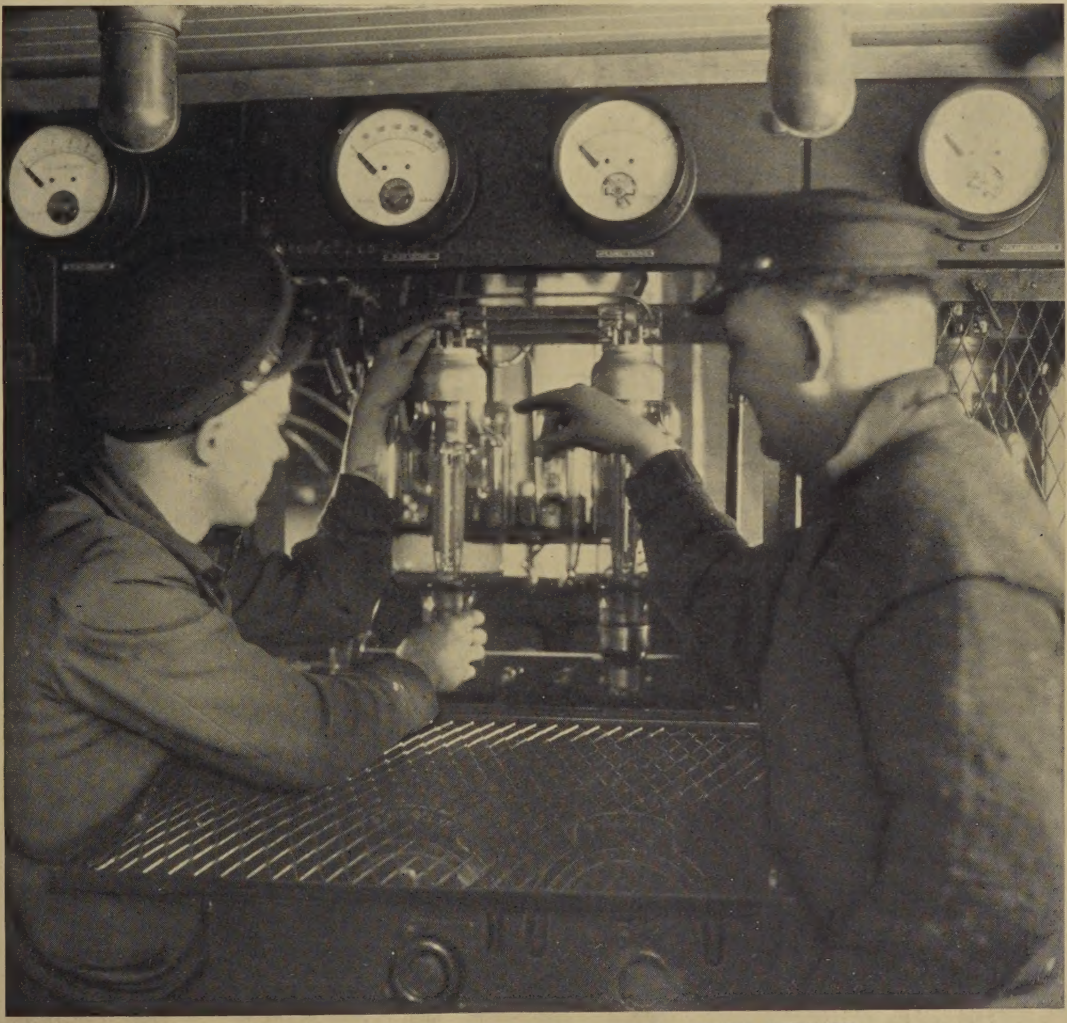
AUGUST, 1925



NEW RADIO EQUIPMENT FOR U. S. COAST GUARD SERVICE

This equipment has an output of two kilowatts, employs seven vacuum tubes of two kinds, those shown being a new type of 1-kw. tube requiring a direct-current plate supply of only 2000 volts. The instruments at the top of the panels indicate the antenna current, plate current, plate voltage, and filament voltage

(See page 549)

In This Issue:
Super-power in Japan
Shaft Whipping Studies
X-ray Crystal Analysis
Metals Through the Microscope
Coast Guard Radio
Internal Friction of Shafts
Compressor Flywheel Design
19th Century Mill Electrification

About one third the tubes for a 52,000 sq. ft. condenser

Condenser Tubes Made By a Condenser Manufacturer

CRESCENT BRAND

CRESCENT BRAND Tubes are made by the Wheeler Condenser & Engineering Company to meet the rigid requirements of condenser practice. So much of the continued satisfactory performance of a condenser depends upon the tubes used therein that constant check must be kept upon the materials and methods of manufacture which result in the longest life. As condenser manufacturers, the Wheeler Company has access to records showing the length of life and service rendered by each lot of tubes, and is in a position to continually improve its procedure and method of manufacturing tubes.

Pure virgin metal, electric furnace melting, laboratory-controlled heat treating and drawing, and the 1000-lb. pressure test are some of the reasons why you should use Crescent Brand Tubes.

WHEELER PRODUCTS INCLUDE

CONDENSERS - ALL TYPES
COOLING TOWERS - HEATERS
STEAM JET AIR PUMPS
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EXPANSION JOINTS
EVAPORATORS
BOILER FEED PUMPS
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TURBINES
CONDENSER TUBES
BRASS & COPPER PIPE

WHEELER CONDENSER & ENGINEERING CO.
149 Broadway, New York
Works - CARTERET, N.J., NEWBURGH, N.Y.

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($6,000,000,000)

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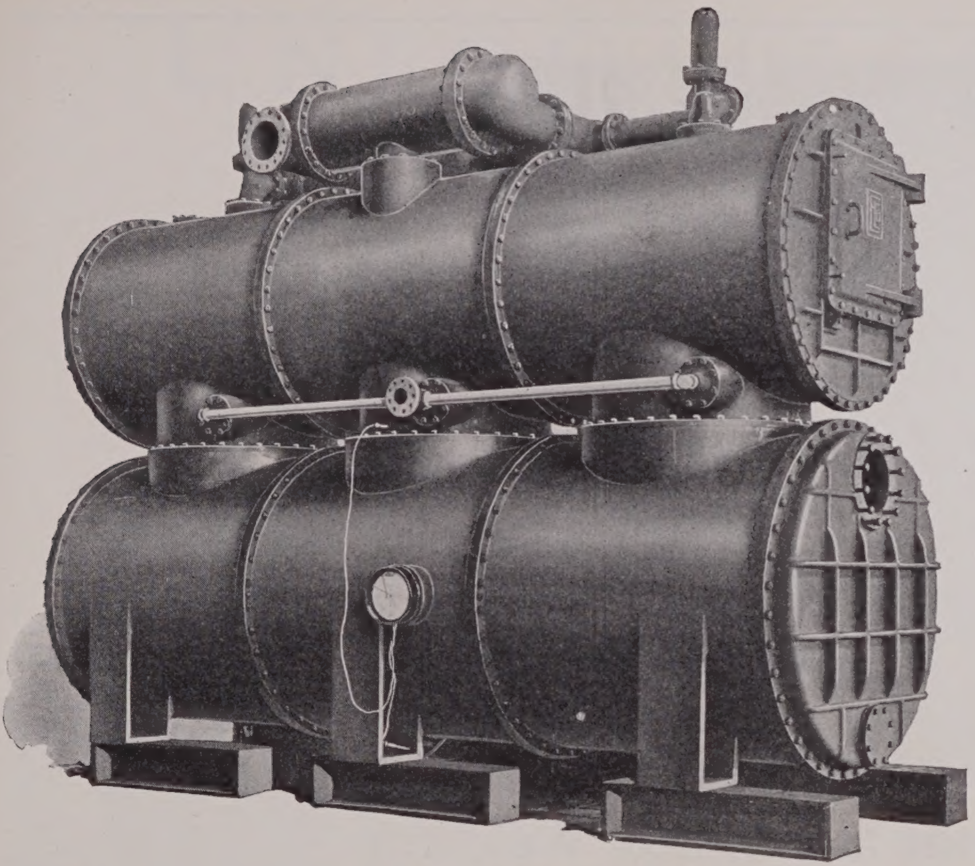
BUILDERS OF

Industrial Plants ***Steam Power Plants*** ***Hydro Developments*** ***Gas Plants*** ***Public Works***



Type "M" Elliott Deaerator unit, 500,000 lbs. per hour capacity, built for the Allegheny County Steam Heating Co. Pittsburgh, Pa.

To protect the World's largest boiler

The illustration shows a shop view of an Elliott Deaerator which is being installed in the Cecil Plant of the Allegheny County Steam Heating Company, Pittsburgh, Pa., in connection with a mammoth boiler which is said to be the largest in the world.*

The Cecil Plant is on the Allegheny River, in the heart of Pittsburgh, and will supply central-station steam-heating service to the downtown business district.

The Elliott Deaerator will protect against corrosion the boiler and the network of steam piping, by furnishing deaerated water and hence air-free steam.

***Some of the data on this boiler: Drums, 60 in. dia. by 34 ft. long; 1173 tubes, 24 ft. long, which together with wall cooling tubes make 6 miles of 4 in. tubing. Heating surface, 32,750 sq. ft. Based on heating surface, the boiler is nominally rated at 3000 h.p., but is capable of operating continuously at 300 per cent of rated capacity. Maximum rate of evaporation, 200 tons per hour, or about 400 per cent of rating. Dwight P. Robinson & Co., Engineers and Constructors.**

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corrosion
in boilers,
economizers,
piping

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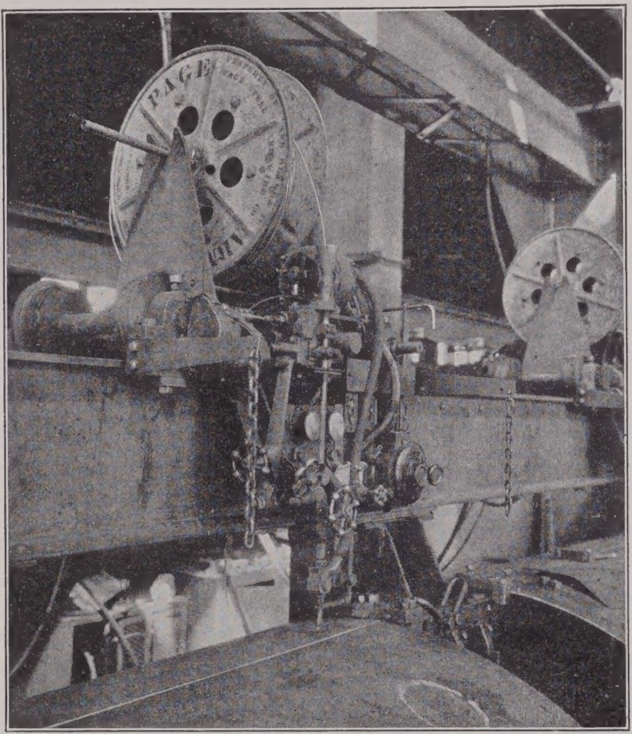
N-835



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TRADE MARK ARMCO REG. U.S. PAT. OFF.

What automatic welding *showed him about rods*

"When I found out by actual test that PAGE-ARMCO rods gave best results in my automatic welder, it started me thinking.

"Perhaps a good welder can do a fair job with less uniform, less free-flowing metal than PAGE-ARMCO, *but it must take him longer to do it.* If the poorer metal makes the machine stutter it must slow up the man.

"I'll pay a little more for an inexpensive thing like welding rods any day to save a welder's time. I'm confident we are now getting better work for *less money.*"

Try PAGE-ARMCO. If you don't have the same experience, let us know. Mail us a card and we will send you an illustrated folder showing how good rods cut welding costs—and arrange for your PAGE-ARMCO test.

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District Offices: Chicago New York Pittsburgh San Francisco

An Associate Company of the American Chain Company, Inc., of Bridgeport, Conn.

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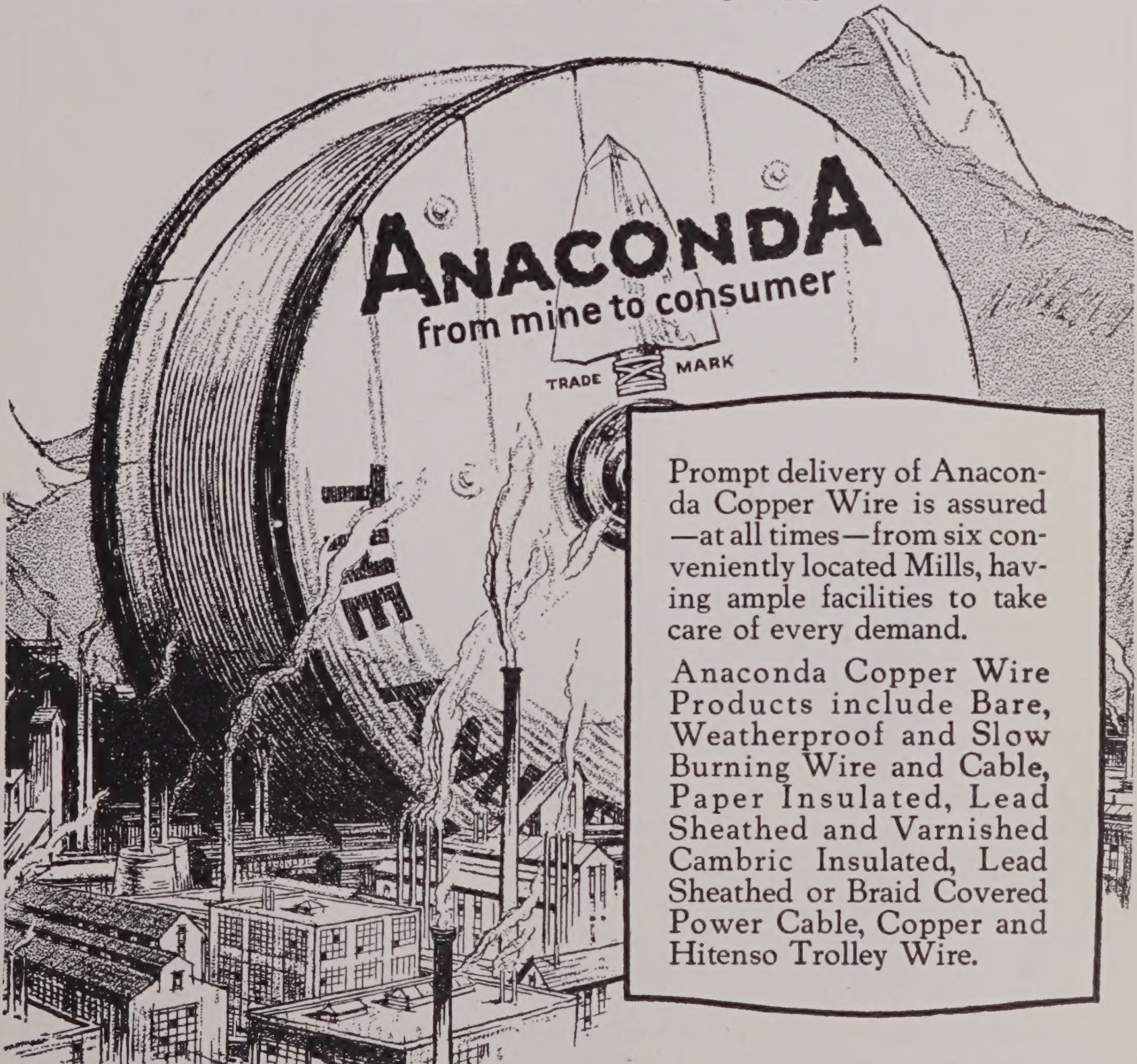
WIRE —Plain and Galvanized—Rope, Telephone, Telegraph, Bond, Strand, Gas Welding Wire and Electrodes

FENCE—Woven Wire for Farm and Railway Right-of-Way, Page Hi-Way Guard, Wire Link Protection for Industrial Plants, Lawns, Schools and Estates, and Factory Partition.

PAGE-ARMCO

Welding Wire and Electrodes

UNEQUALLED SERVICE



Prompt delivery of Anaconda Copper Wire is assured—at all times—from six conveniently located Mills, having ample facilities to take care of every demand.

Anaconda Copper Wire Products include Bare, Weatherproof and Slow Burning Wire and Cable, Paper Insulated, Lead Sheathed and Varnished Cambric Insulated, Lead Sheathed or Braid Covered Power Cable, Copper and Hitenso Trolley Wire.

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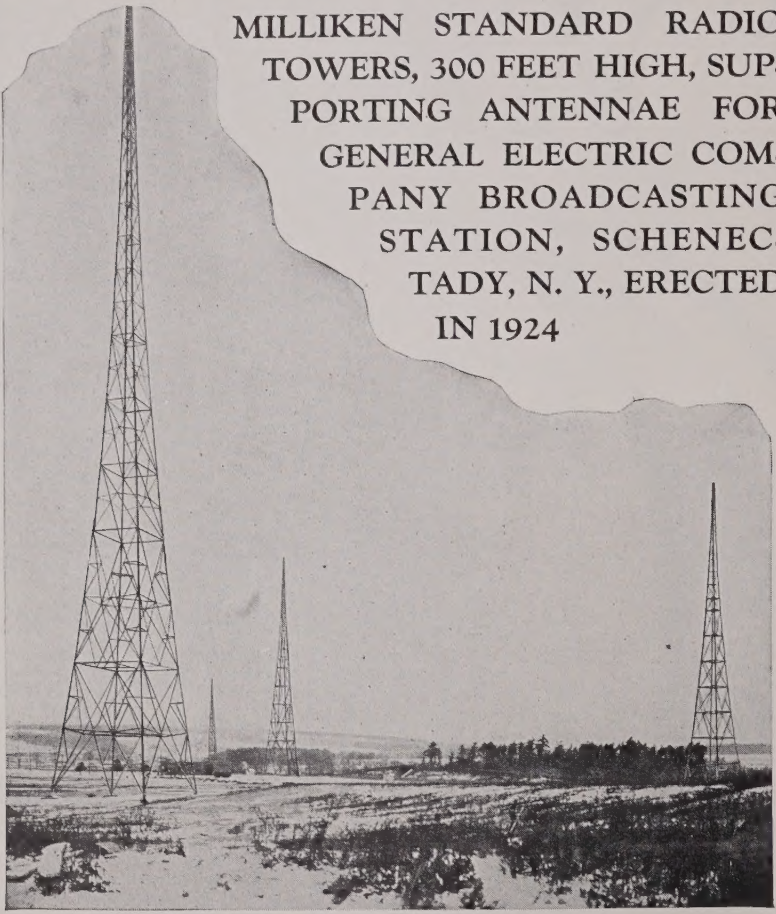
MILLIKEN STANDARD RADIO TOWERS, 300 FEET HIGH, SUPPORTING ANTENNAE FOR GENERAL ELECTRIC COMPANY BROADCASTING STATION, SCHENECTADY, N. Y., ERECTED IN 1924



MILLIKEN Standard Radio Towers, 300 feet high, are being used by the General Electric Company at its new experimental broadcasting station, Schenectady. These towers were selected by the leading broadcasting station in the world for stability, reliability, long life and economy, to secure the best results in long distance service.

The General Electric Company leads in all electrical development and specialized broadcasting equipment. This station represents the last word in experimental broadcasting.

MILLIKEN Standard Radio Towers are hot galvanized throughout. They are carried in stock for immediate shipment and are furnished in heights ranging from 66 feet to 300 feet.

Milliken towers are used also at such important broadcasting stations as—

WPG —Municipal Station, Atlantic City, N. J.
WEAF—American Telephone and Telegraph Co., New York
WSAI —United States Playing Card Co., Cincinnati
WEEI —Edison Electric Illuminating Co., Boston
WBZ —Westinghouse Electric & Mfg. Co., Springfield, Mass.
WHAZ —Rensselaer Polytechnic Institute, Troy, N. Y.
WMAF—Round Hills Radio Corporation, Dartmouth, Mass.
WCX —Detroit Edison Co., Detroit
WGBS —Gimbel Brothers, New York
WAHG—A. H. Grebe Co., Brooklyn, N. Y.

Catalogs in English and Spanish will be furnished on request.

MILLIKEN BROTHERS MFG. CO., Inc.

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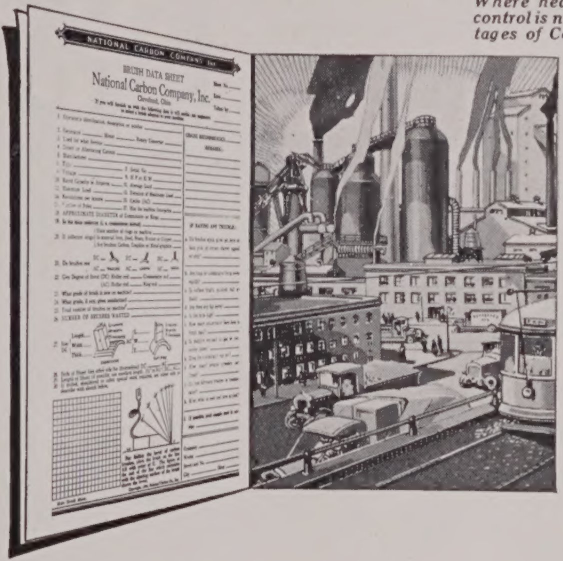
Also, Manufacturers of Transmission Towers and MILLIKEN BUILDINGS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Cleveland, Ohio

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Accompanying view shows one of Four single-runner, vertical shaft, cast iron scroll-case Hydraulic Turbine Units now in successful operation in the Tugalo Plant of Georgia Railway & Power Co.

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Each turbine develops 22,000 H.P. at 171.4 Rev. under 150 ft. head and is direct-connected to a 12,500 kw. General Electric Generator.

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The Manufacturing
Skill enabling us
to render REAL
SERVICE.

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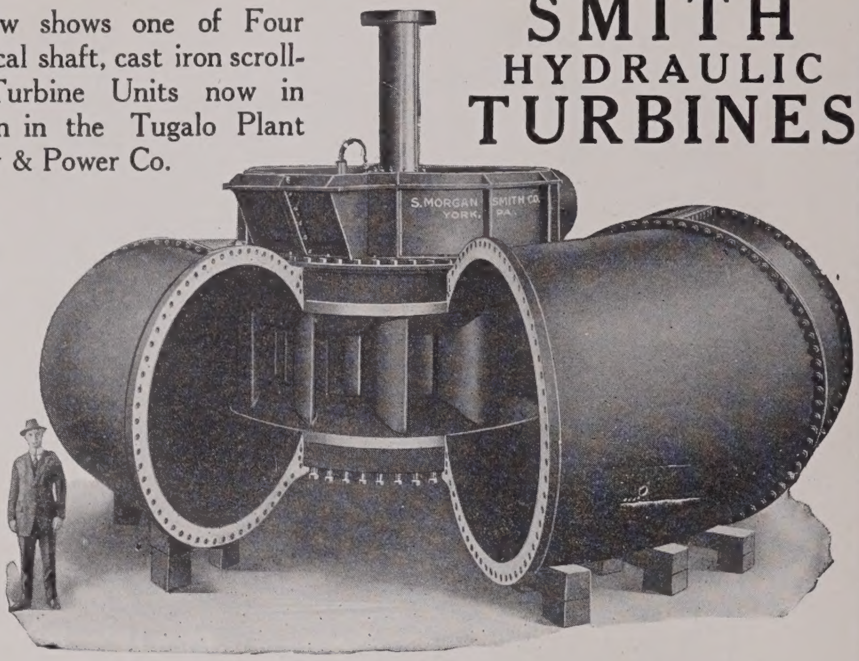


S. Morgan Smith Co., York, Pa.

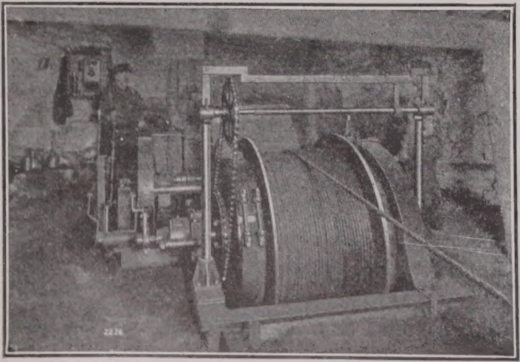
LIDGERWOOD MINE HOISTS

ELECTRIC in all sizes

STEAM up to 1000 H.P.

Illustration shows a slope hoist, operating an underground incline 1700 feet long. It has been in use by The Spencer Coal Co. for a number of years, and has given excellent satisfaction, both in service performed, and its wearing quality.

WE BUILD mine hoists, both steam and electric, in types to meet every kind of mine service.



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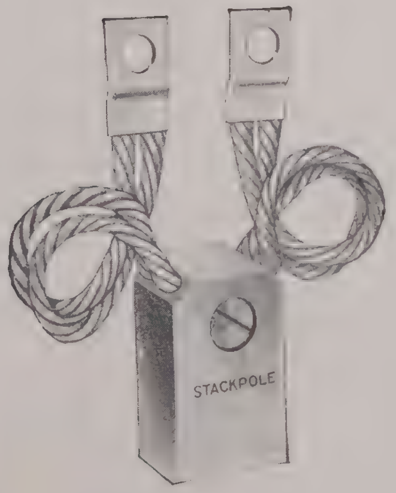
It's Like Friendship



A feeling exists between a commutator and its Stackpole Brush—a feeling of mutual respect that amounts to friendship.

Chattering, high mica, heating, flat spots—*Stackpole Carbon Brushes* prevent them all. Smooth, glossy commutators are always to be found wherever Stackpoles are installed.

No matter where you use Carbon Brushes—you'll find a type of Stackpole Brush admirably suited for your purpose. Let Stackpole Engineers make a study of your brush requirements and show you how you can obtain better commutation and longer life with *Stackpole Carbon Brushes.*

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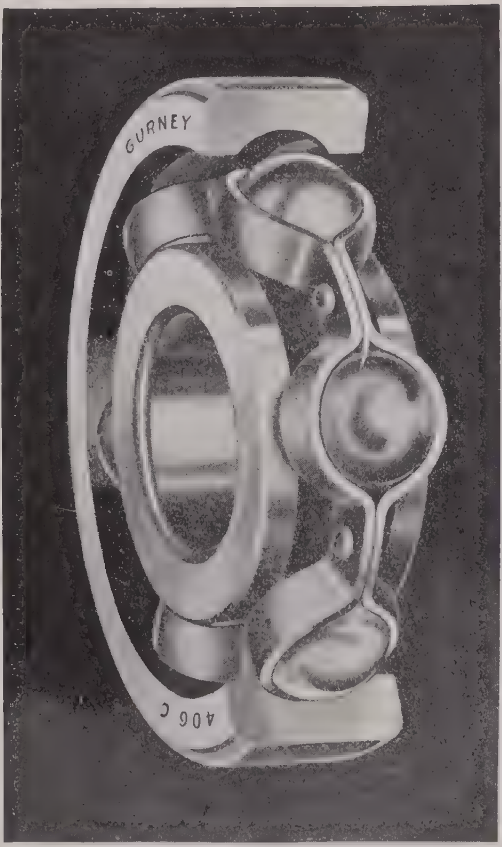
CARBON BRUSHES

STACKPOLE CARBON COMPANY
ST. MARYS PA.



Accuracy and Speed

Gurney Deep Groove bearings, Type C, are capable of extremely high speeds as they are held to the closest possible limit of accuracy. This accuracy is maintained in every manufacturing department where inspections are held after each operation. High quality Chrome Alloy Steel rings and balls, with an extra heavy pressed steel ball retainer, are the main factors toward longer bearing life and increased service. Deep, uninterrupted raceways make the bearings fool proof in mounting as either shoulder can be applied to the load.

1831

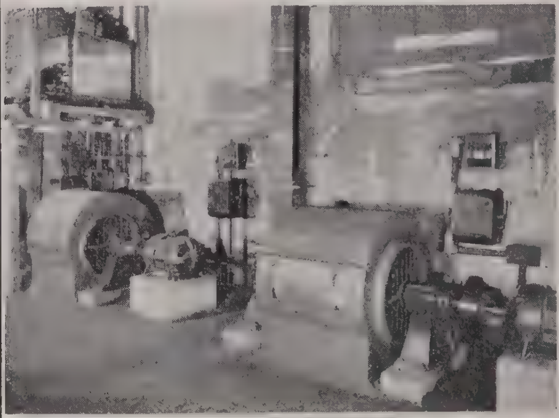
Write for further information

Marlin-Rockwell
Corp.
Jamestown, N. Y.

GURNEY TYPE C BALL BEARINGS

Thousands saved by automatic stokers and "Buffalo" Fans

WHEN the boilers were changed over recently from hand-fired to automatic stokers at the plant of John Bromley & Sons, Inc., at Philadelphia, three size 4½ Buffalo Turbo-Conoidal Stoker Fans were installed to provide draft.



Henry J. Fay, Chief Engineer at the above company says:

> "The use of this new equipment has enabled us to eliminate 4 men formerly required for hand firing. This saving, together with a much larger one due to the much more perfect combustion and resulting fuel economy, will amount to many thousands of dollars per year, and pay for the equipment in a very short time.
>
> "With our automatic stokers and fans we have been able to operate on 2 boilers most of the time instead of having to use 3 or 4. We can now get twice the rated horsepower from our boilers for 10-hour periods."

Many power plants now using natural draft can greatly increase their boiler output by installing Buffalo forced draft fans.

Buffalo Forge Company
170 Mortimer Street Buffalo, N. Y.

New Departure Ball Bearings

THE cost of motor repairs found to be directly or indirectly due to bearings is leading an increasing number of motor users to consider ball bearings.

How New Departure Ball Bearings reduce your present outlay for maintenance is tersely stated in two folders which will be sent upon request.

For engineers, New Departure's "Special Bulletins on Electrical Machinery" will prove interesting and helpful. This is part of an engineering bulletin service issued monthly to those in a position to use it to advantage.

THE NEW DEPARATURE MANUFACTURING COMPANY
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BALL BEARING APPLICATION
The New Departure Mfg. Company
BRISTOL, CONNECTICUT
NEW DEPARTURE BALL BEARINGS
Ball Bearings in Motor Driven Elevator Gearing

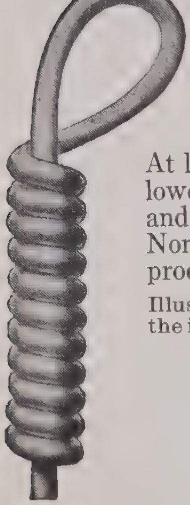
184

"INDIANA"

Double Galvanized Telephone and Telegraph Wire

CRAPO PATENTS

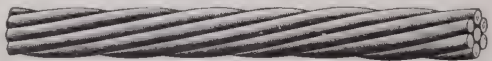
Non-Peeling—Non-Cracking



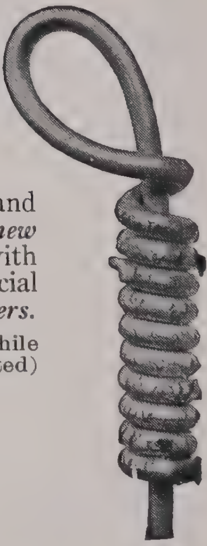
At last the Telephone and Electrical Industry is assured longer life and lower maintenance on galvanized wire construction through our *new* and *improved* patented Galvanizing Process, which insures a wire with Non-Peeling and Non-Cracking Zinc Coating. Now in full commercial production. Carried in stock by Representative *Supply Jobbers.*

Illustration at right shows what happens to old process galvanizing, while the illustration at left shows assured results of CRAPO PROCESS—(patented)

Galvanized Steel Strand



Standard or Commercial, Siemens-Martin, High Strength and Extra High Strength Grades



Indiana Steel & Wire Company, - - Muncie, Indiana

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PRECISION ROLLER BEARINGS

For the heaviest loads and hardest motor service—under conditions where no other bearings will stand up.

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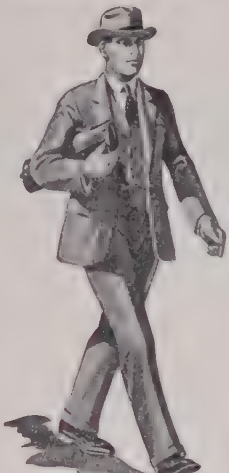

Motors, for Instance

THIS man sees more different kinds of machinery in a week than you and I see in a year. He discusses cement mills and shafting, pumps and gang saws with engineers in every conceivable industry. And there is common to all machines one problem on which he speaks with authority and they listen with respectful interest. When it comes to lubrication they are impressed with the realization that he is familiar with every conceivable angle including the conditions that are encountered.

Take electric motors and generators as an example. High speed and heavy duty are both met with; conditions of heat and cold are not uncommon, and yet the hardest problem is not to lubricate but to prevent the gradual ruining of armatures and mica segments through the creepage of oil. This can be accomplished by the correct application of Keystone Liquid Grease.

No matter what your industry or what conditions prevail, this Keystone Lubrication Engineer can offer advice that is worth considering. You will not be obligated in any way.

KEYSTONE LUBRICATING CO.
Est. 1884
Philadelphia, Pa., **at 21st and Clearfield Streets**
Branches and warehouses in principal cities of the country

KEYSTONE GREASE

Keystone Safety System of Keystone Grease Lubrication

DIAMOND SOOT BLOWERS

for all types of boilers

Save 4 to 8% fuel.

Save labor and labor turnover.

Keep boilers on the line longer.

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10340 Oakland Avenue
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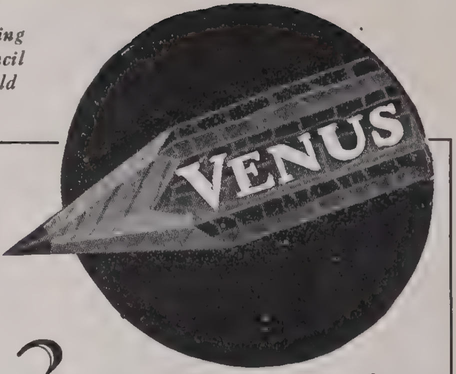

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SPEER—the name of quality

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For a thousand insulation problems

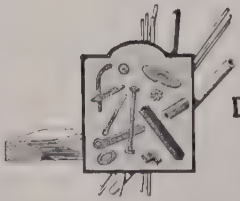
DIAMOND FIBRE and CELORON

ADAPTABLE, easily worked, great tensile and dielectric strength.

FIBRE—in sheets, rods and tubes or in special shapes to specifications.

CELORON—in sheets, in panels, in rods, in special shapes, in tubes, in various finishes.

Information is only a matter of request

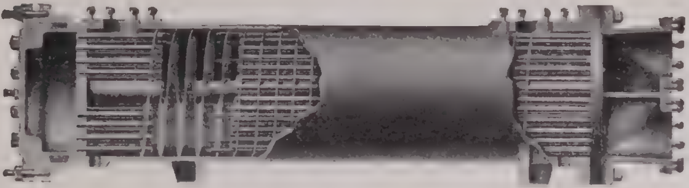


Diamond State Fibre Company
The oldest and largest manufacturer in the vulcanized fibre-laminated technical products industry
Bridgeport, Pa., and Chicago, Ill.

CELORON

Diamond-F

Keeps Turbine Oil Cool—



The G-R Multiwhirl Cooler

Keeps turbine bearing and reduction gear oil at the temperature for proper lubricating effect. A safeguard against overheated bearings and a help to greater oil economy.

Over 2000 in Use

Send the coupon for full information

THE GRISCOM-RUSSELL COMPANY

2140 West St. Building, New York

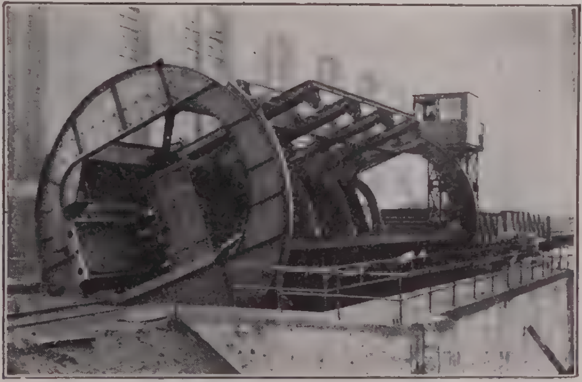
BRANCHES IN PRINCIPAL CITIES

Name ....

Address ....

The Griscom-Russell Company,
2140 West Street Bldg., New York.
Gentlemen:
Please send us a copy of bulletin
describing the G-R Multi-
whirl Cooler.

Latest Development in Revolving Car Dumpers



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Utah Copper Company (2 Machines)

It meets the demand for a dumper of simple construction, small investment, high efficiency, low operating cost and a minimum of labor.

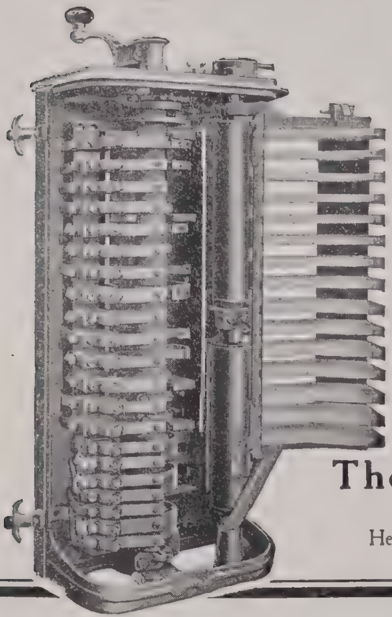
Built in lengths of 30, 40, 50 and 60 feet for handling cars from 6 ft. 6 in. to 13 ft. 0 in. high and from 9 ft. 0 in. to 10 ft. 9 in. wide and loaded capacities up to 320,000 lbs. gross weight.

The Wellman-Seaver-Morgan Company

Cleveland, Ohio, U. S. A.

B
T-H

Tramcar Controllers



The B.T-H. (B510) tramcar controller illustrated has many important features of special interest. Among these may be mentioned the adjustable fingers with renewable contact tips; individual blow-out coils for each finger ensuring the most rapid quenching of the arc; cross-field magnetic braking is employed and this is effective in either direction and irrespective of the position of the reversing handle. All cable connections are readily accessible without removing the controller barrel and a motor cut-out switch, operated from the cap-plate, is incorporated to simplify testing the motors individually without opening the controller.

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE   Editor, JOHN R. HEWETT   Associate Editor, E. C. SANDERS

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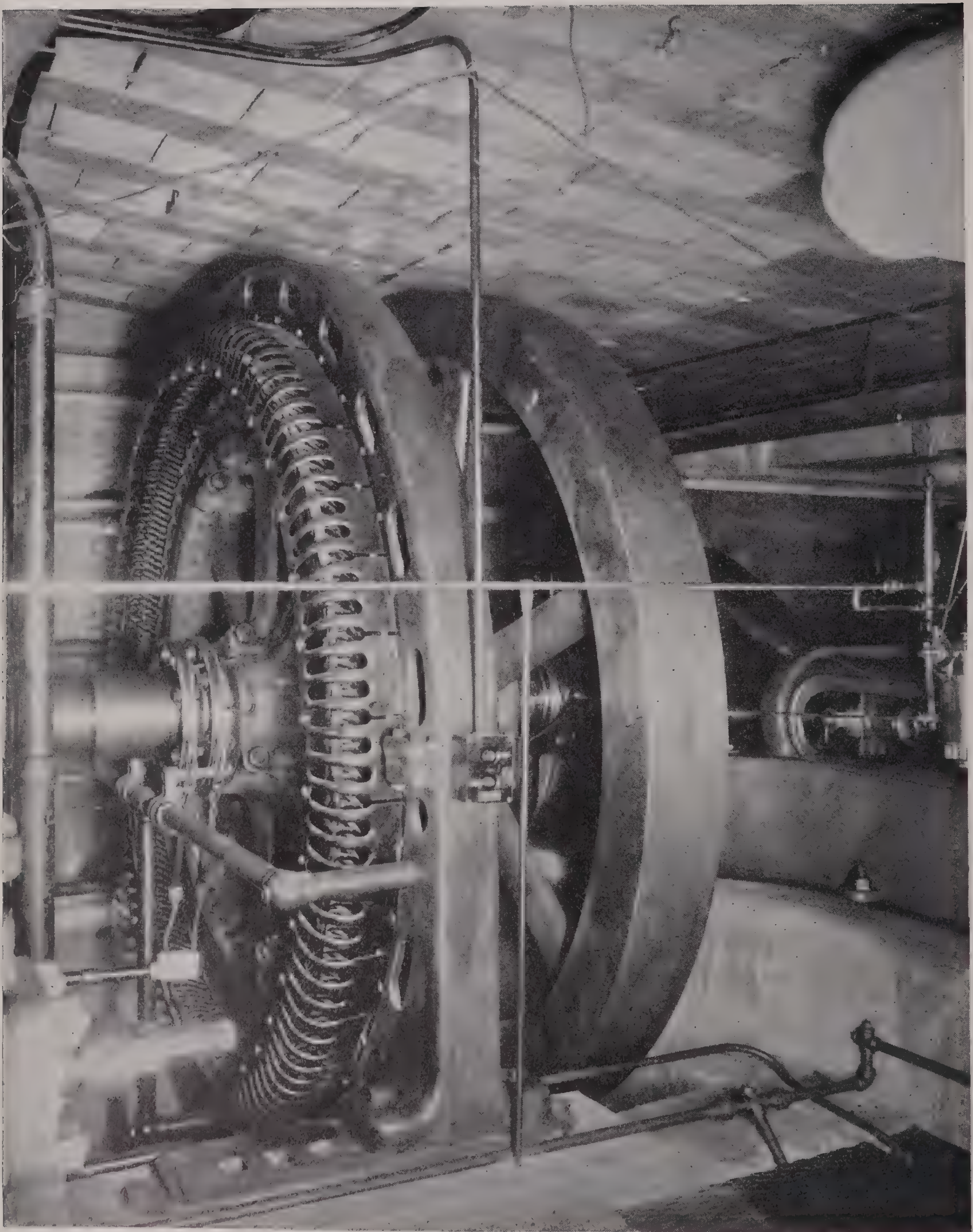

A TYPICAL SYNCHRONOUS MOTOR COMPRESSOR DRIVE

Problems in flywheel effects can readily be computed by the method outlined in Mr. Stevenson's article, appearing on page 580

GENERAL ELECTRIC REVIEW

KNOWLEDGE GAINED OF METALS BY AID OF THE MICROSCOPE

The ever-increasing demand for a better product necessitates using the best and most perfect materials in the manufacture of machinery and appliances of all descriptions. To create and maintain a satisfactory market for his product, a manufacturer must fulfill one or possibly both of the following specifications: The product must either be superior to that made by any other firm, or it must possess all the main characteristics of the competitors' product and be lower in price.

Such requirements lead to refinements in manufacturing and to almost infallible standardization. The matter of refinements is very ably taken care of by the production engineer; and the metallographer furnishes a valuable service in the general scheme of standardizing both the material purchased and the finished product.

In the latter field of activity, research with the microscope is very gratifying. The pioneer metallographic work done by Sorby, Osmond, and Roberts-Austin has been an inspiration. As the result of the zeal with which the later investigations have been conducted, the science has attained a thoroughly practical state of usefulness within a few decades.

Chemistry gives us invaluable knowledge, but it leaves us in the dark with respect to the manner in which the various elements and compounds are related to each other in a metallic aggregate. For example, consider two pieces of steel, each having the same chemical composition and containing approximately equal parts of pearlite and ferrite. Chemically they are identical; physically they have properties which vary greatly. If the metallurgist's knowledge should stop here he would find himself in a sorry predicament. With the microscope, however, he can determine the exact cause for this variation.

By a careful examination of this sort it is possible to determine with an almost unbelievable degree of accuracy the chemical composition, the hardness, and the mechanical and heat treatment which a specimen has received, and also the segregation which has taken place. From these data many of the mechanical properties can be predicted and the suitability of the material determined. In fact, a carefully performed microscopic examination will often solve a perplexing problem with a resulting increased production and elimination of waste due to faulty or improper treatment during any part of the manufacturing process.

While the carbon content, brittleness, grain size, segregation, blowholes, and mechanical treatment can be roughly determined in the unprepared specimen, we can push our examination further and get some conception as to homogeneity, and to differences in methods of production, by the microscopic examination of a specimen which has been roughly polished (i.e., ground to a fair degree of smoothness) and then etched. However, to make an accurate study of all these factors, it is necessary that the specimen be highly polished and etched. Upon examining such a specimen it is also possible to detect the minute and important details such as constituents of various colors and hardness, and many other factors of metallurgical significance.

The field of application is a very fertile one, particularly when high magnifications are employed. This is especially true of the high-speed and complex-alloy steels. There is great need for knowing how the various carbides occur, and how their characteristic formations appear under the microscope. To this end we are including in this issue the first part of a serial article which describes the polishing of the specimen, the etching operation, and how the examination under the microscope may best be conducted.

Super-power in Japan

By Minoru Fukuda

Chief Engineer, The Toho Electric Power Company, Tokyo, Japan

We are in the United States so diversified in geographic location, industrial development, and abundance of natural resources, that the present-day tendency to unify electrical systems must find expression in the establishment of various separate zones, each fitted to the peculiar conditions at hand. In Japan, however, the geography is roughly divided into a mountainous region surrounded by a belt of densely populated lowlands. The proposition of unifying the power systems into one "Super-power" network is therefore more straightforward. Mr. Fukuda, as chief engineer of one of Japan's largest electric power companies, presents in the following article a comprehensive plan for the establishment of "Super-power" in that country, bringing in all of those factors which attend this problem universally, as well as certain special considerations that are local.—Editor.

In order to raise the standard of living and give its people more enjoyment and comfort, Japan must improve its economic conditions. Since Japan's agricultural land is small and its mineral resources poor, its further economic progress depends on the progress and development of its manufacturing industries. In fact, the manufacturing industries will be the sole foundation of the country and the bread of its ever-increasing population. The country's manufacturing industries in turn depend upon the effective utilization of its motive power and the development of reliable transportation systems.

Although we have limited deposits of coal, at the present rate of consumption they will not last more than two or three score years. Therefore, we cannot rely on the country's mineral resources for future industrial progress. What coal and petroleum we have now must be reserved for future use as much as possible. Japan is, however, gifted with rapid mountain rivers, narrow natural gorges, and abundant rainfall. By harnessing our natural hydraulic resources, we shall have an unlimited supply of motive power in electricity for all industries and transportation systems. Hydro-electric power, when combined with steam electric power, will give the most reliable and cheapest supply of electricity.

Most of the country s waterpower sites are in mountain valleys far away from the load centers, and consequently the electric energy must be transmitted over high-voltage transmission lines to the factories, stores, and houses. Moreover, water rights are possessed by many different companies and individuals. It is, therefore, natural that with the development of hydro-electric power, many transmission lines will be constructed in parallel in unnecessary duplication. Some method must be devised, before it is too late, to eliminate this duplication of the transmission lines. This is the reason why we are urging the construction of a so-called super-power system—trunk transmission lines by which all power plants may be inter-connected. With a super-power system, production cost becomes lower, service becomes more reliable, diversity factors are higher, and therefore the result will be better utilization of our power resources. Cheaper and more reliable power will be a great factor in our industrial progress. The time for discussing the merits of a super-power system has passed. A definite step must be taken now for its realization, lest we should regret in the future.

In the following paragraphs the writer will try to show the facts in connection with the super-power system in Japan. If the industrial leaders can be made to see the necessity of such a system and expedite its progress the whole country will be benefited.

Territory Covered by Proposed Super-power System

The super-power system in Japan may be spread over the territory stretching from Fukushima and Niigata prefectures on the east to Hyogo Prefecture on the west, including some of the largest cities and 21 prefectures. In this territory are located three of the largest load centers in the country, namely, Kei-Hin (around Tokyo and Yokohama), Chukyo (around Nagoya) and Kei-Han (around Kyoto, Osaka and Kobe). There are also many important power plant sites capable of profitable development and interconnection. Super-power systems in other sections of the country must be investigated from economic and technical points of view before actual discussion can take place.

The territory for the proposed super-power system may be divided into two zones.

1. Eastern zone with center in Kei-Hin district (Tokyo and Yokohama).
2. Western zone with center in Chukyo district (Nagoya) and Kei-Han distric (Kyoto, Osaka and Kobe).

These two zones are geographically separated by the Japanese Alps and the Tenryu River.

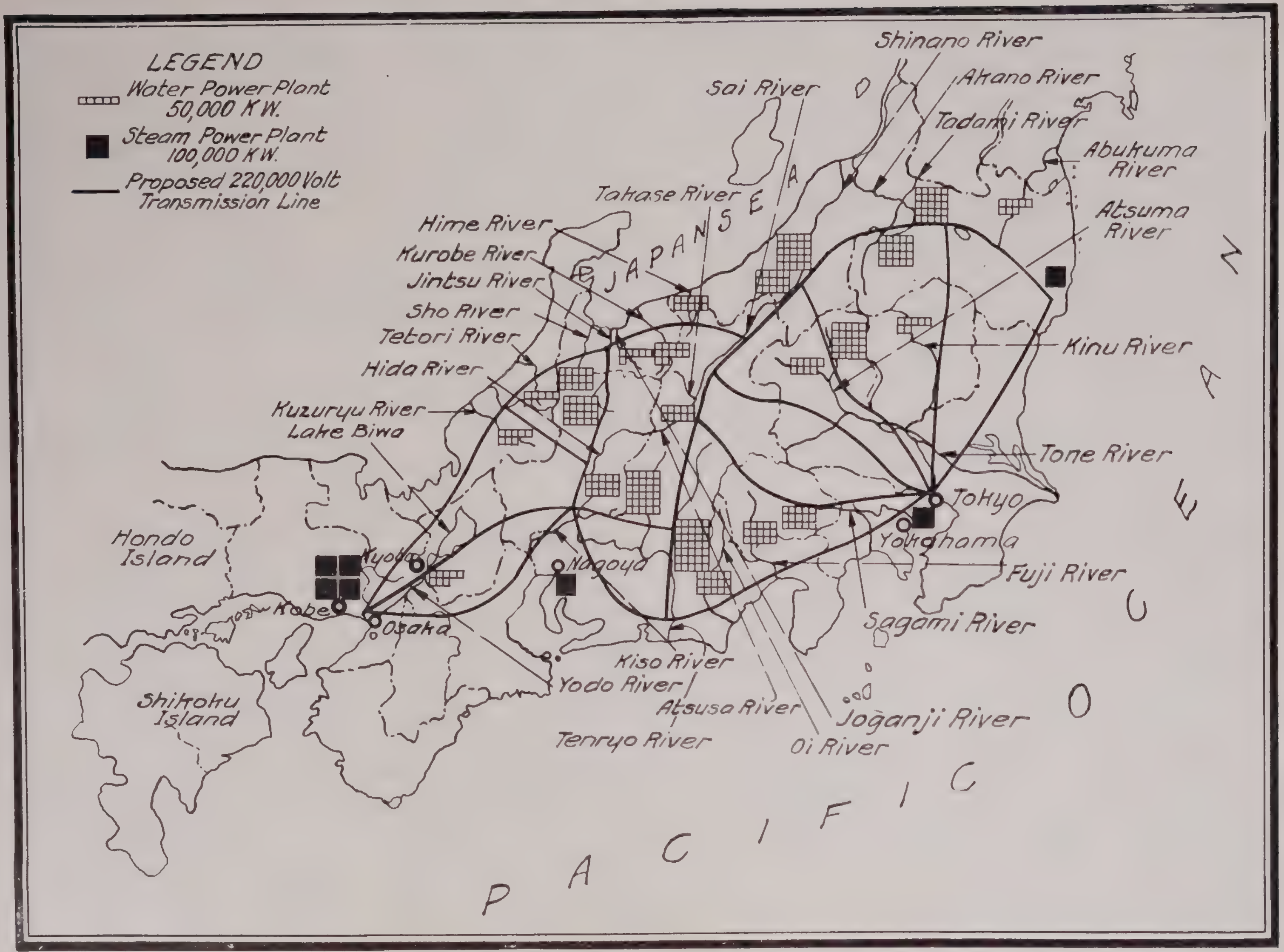

Fig. 1. Map Showing the Proposed Location of Transmission Lines, Steam and Hydro-electric Generating Stations, and Load Centers for the Super-power System

Increase of Energy Demand in Super-power Zone

It is very difficult to forecast the future demand for electric energy, because many new fields of its application are initiated every year. But, judging from past experiences as shown by statistics, the future electric energy demand would be as in Table I.

TABLE I

Year	Eastern System	Western System	Total
1922	530,000 kw.	500,000 kw.	1,030,000 kw.
1928	820,000 kw.	790,000 kw.	1,610,000 kw.
1933	1,150,000 kw.	1,120,000 kw.	2,270,000 kw.
1938	1,500,000 kw.	1,470,000 kw.	2,970,000 kw.
1943	2,000,000 kw.	2,000,000 kw.	4,000,000 kw.

Available Power

The available power of the principal rivers in the proposed super-power zones is shown by Table II. This does not, however, include any river whose available power is less than 10,000 kw. Since the Tenryu River is situated on the boundary line of the two zones, its available power will be divided equally between them.

Steam Power Plants in the System

Interconnection of power generating facilities in the super-power system depends on the locations of available waterpowers, load centers and coal mines, and the geographical condition of the localities. In Japan waterpower will be the principal source of energy for the super-power system and steam power will be used as the auxiliary during the dry season in winter, when the available water power decreases about 20 per cent. In other words, approximately 700,000 kw. of steam power will be required for the system.

Hydraulic		3,500,000 kw.
Steam		
Osaka district	400,000	
Nagoya district	100,000	
Tokyo district	100,000	
Taira district	100,000	
		700,000 kw.

Most of the large steam power plants will be located in western sections, where transportation facilities for Kyushu and Manchurian coal are favorable. For the power plant in the Tokyo District, the Hokkaido coal or imported oil will chiefly be used. In the Taira district Joban coal, which is mined there, will be used.

Planning of Transmission System

Locations of the transmission lines, which connect each hydro and steam power plant with load centers, are shown on the map, in Fig. 1. These locations may need to be changed a little, on account of the geographical condition, but it is thought that the best plan is shown on the map.

Advantages of Super-power System

From the economic point of view, there are many advantages in the super-power system, such as reliable and constant supply of power which, although it cannot be shown numerically in dollars and cents, is an important asset to a power company in winning the confidence of the consumers. The point that must not be overlooked in the proposed super-power system is that there is no intention of spending millions of dollars for the construction of the special transmission lines. The proposed plan calls for nothing more than systematic interconnection of the large individual transmission systems that may be built in the future, for the economical utilization of the power resources.

TABLE II

Name of River	Province	Potential Power in Kw.
	EASTERN SYSTEM	
Abukuma	Fukushima	80,000
Tadami	Fukushima	200,000
Akano	Fukushima and Niigata	250,000
Shinano	Niigata	400,000
Kinu	Tochigi	70,000
Tone	Gumma	250,000
Atsuma	Gumma	90,000
Sagami	Yamanashi and Kanagawa	150,000
Fuji	Yamanashi and Shizuoka	150,000
Ohi	Shizuoka	150,000
Sai, Takase, and Atsusa	Nagano	100,000
Hime	Nagano and Niigata	100,000
Tenryu	Nagano and Shizuoka	175,000
Total		2,165,000
	WESTERN SYSTEM	
Tenryu	Nagano and Shizuoka	175,000
Kiso	Nagano and Gifu	300,000
Hida	Gifu	140,000
Sho	Gifu and Toyama	150,000
Jintsu	Gifu and Toyama	200,000
Joganji	Toyama	60,000
Kurobe	Toyama	120,000
Chitori	Ishikawa	60,000
Kuzuryu	Fukui	80,000
Uji	Kyoto	80,000
Total		1,365,000
Grand Total		3,530,000

(*A*) *Individual and Interconnected Transmission Systems*

Technically, any quantity of power can be transmitted over any distance, but not commercially. If, however, several systems are combined into a so-called super-power system, we can transmit power very much more cheaply and, therefore, the cost of power in the load centers becomes less.

Although the advantages of the interconnected system cannot be shown by accurate figures, the calculation given in Table III will give a rough idea. Suppose 100,000 kw. and 200,000 kw. were to be transmitted over a distance of 200 miles; a 154,000-volt line is more economical for the former, and a 220,000-volt line for the latter. But as shown in the calculation, the construction cost per kw. for a 200,000-kw. 220,000-volt line is lower.

The construction cost per kw. of a 220-kv. line is $25 cheaper than that of the 154-kv. line. This will make a total saving of $84,000,000 for transmitting 3,500,000-kw. of power within the proposed super-power system. The transmission expense for a 154-kv. line is 0.3 cent per kw-hr. while that for a 220-kv. line is 0.25 cent or with a 220-kv. line there will be a saving of 0.05 cent per kw-hr. Assuming 70 per cent load factor for 3,500,000 kw. there will be a total saving of about $1,050,000 per year in the transmission line expense.

In the above calculation it is assumed that the average distance over which power will be transmitted is 200 miles, and the amount of power to be transmitted is 200,000 kw. Of course, in actual practice the transmission distance as well as the amount of power may vary to a certain extent.

TABLE III (1)

ITEMS	100,000 Kw. Cost in Dollars	200,000 Kw. Cost in Dollars
Transforming Substations	5,950,000	13,050,000
Transmission line.......	8,000,000	10,000,000
Total.............	13,950,000	23,050,000
Average transmission construction expenses per kw..................	$140	$115

The rainfall and, therefore, the power generating capacities of different localities, vary according to the time of the year. With a super-power system, however, power shortage in any locality can be equalized by the surplus power in other sections. During the dry season the available power of a Japanese river decreases about 40 per cent from normal available power. The average decrease of all rivers superposed at any time is, however, only 20 per cent. Therefore, with the interconnected system, our power resources can be used 20 per cent more effectively during the dry season. In other words, the capacity of the auxiliary steam power plants can be made 20 per cent smaller, which will result in a saving of $6,150,000 per year in power generating expense.

TABLE IV

Hydro plants built for	Normal Stream Flow 3,500,000 Kw.	Minimum Stream Flow 2,800,000 Kw.
CONSTRUCTION COSTS		
Hydro power plants...	$875,000,000	$770,000,000
Steam power plants...	52,500,000	52,500,000
Total construction cost	$927,500,000	$822,500,000
OPERATING EXPENSES		
Yearly load factor....	10 per cent	60 per cent
Annual generating expense............	$6,150,000	$33,150,000

(*B*) *Combined Use of Hydro and Steam Power*

The power generating capacity of hydropower plants in Japan decreases in the dry season, which comes twice a year for short periods in the winter and summer. It is, therefore, more economical to design hydropower plants based on normal stream flow, and to meet power shortages in the dry season by auxiliary steam plants. Under such a condition the generating capacity in the superpower system will be 3,500,000 kw. in hydro plants and 700,000 kw. in steam plants. If power plants are based on minimum stream flow, the capacity of hydro plants will be 2,800,000 kw. and that of steam plants, 700,000 kw.

A comparison in construction costs and operating expenses for these two cases is given in Table IV.

Thus, with the hydro power plants designed for normal stream flow, the construction cost of the generating facilities will be $105,000,000 higher, but there will be a saving of $27,000,000 per year in operating expenses.

(*C*) *Super-power System and Diversity Factor*

The peak load of the industrial and residential districts comes in the daytime, while that of the business district comes at night. In the cities the electric energy demand increases in the winter, while in the farming districts the demand increases during the summer. It is likely that Tokyo will be the center of politics and finance, and Kansai the industrial center, and therefore their peak loads, coming at different times of day, will not interfere. Electric energy will also find new fields of application in farms, industries, homes, railways, and elsewhere. These diverse power demands in different districts at different times of the day and year can be utilized advantageously by the super-power system. At present the diversity factor in Japan is between 1.03 and 1.04, but with the Super-power plan of interconnecting different systems, it is expected that the diversity factor would be increased by at least 10 per cent. To be conservative, assume that the increase will be 5 per cent instead of 10 per cent. This means a saving of 170,000 kw. of power-generating equipment, and $8,500,000 per year approximately in operating expense.

---

(1) In this table and throughout the remainder of the article, cost figures are given in dollars, based upon the Japanese equivalent of one dollar equals two yen.

(*D*) *Power for Electric Traction*

It is generally said that the load curve of an electric street railway is flat. This is because the maximum demands of different cars come at different times. For example, on March 28, 1922, there were 1300 cars operating on the Tokyo Municipal Railway. The peak load demand of the system was 18,300 kw., whereas, if all cars had started at the same time, it would have been 130,000 kw., because the average capacity of each car is 50 kw. and it takes at least 100 kw. for starting. The same flat load curve could be obtained on the electrified steam railroads, if their power were supplied from one large interconnected system.

In other words, if all the required power is furnished by one system, there will be carried only sufficient generating capacity to supply the peak demand, i.e., 18,300 kw. However, if more than one system supplies the power then the generating capacity of each system must be capable of supplying its own peak load. Thus interconnection is economical in total installed capacity.

In all cases, if power is supplied from several independent systems, the advantage of diversified load is much less available. Good diversity loads could be obtained if power for the present electric roads and the steam railways to be electrified were supplied from a large power source.

(*E*) *Emergency Concentration of Power*

Concentration of power at a load center for an emergency can only be done by a super-power system. (Of course, the extent to which power can be concentrated depends on the demands of the various other load centers.) By using reserve transformers, 300,000 kw. to 350,000 kw. of power can be concentrated for a short time around Tokyo, Yokohama or Osaka. With special arrangements, any amount of power can be concentrated at any load center.

(*F*) *Simplification of Complicated Transmission Networks*

The transmission system in Japan is already so complicated that there may be several lines between two places where one line of greater capacity would suffice. If different systems were interconnected by a super-power system, there would be a large saving in transmission equipments.

(*G*) *Effective Utilization of Water Reservoirs*

Water reservoirs are already being utilized by some systems to meet the daily peak or the power shortage. With the super-power system, however, water in such lakes as the Inawashiro in the north, the Kiso Otaki in central Japan, and the Biwa in the west may be used more effectively for the benefit of all districts within the system.

(*H*) *220,000-volt Interconnected System*

According to the present transmission conditions, the territory may be divided into two zones, Eastern and Western. If the present system should be continued in the future, 154,000-volt lines already under operation will be sufficient. But in order to fulfill the object of the super-power system, a 154,000-volt line is uneconomical, because power must be transmitted over a long distance from east to west. The available power of the Eastern Zone is estimated at 2,165,000 kw. and that of the Western 1,365,000 kw.; in other words, 400,000 kw. of electric energy must be transmitted from east to west. The boundary of the two zones equally divides the amount of power demand; the available power in the two zones differs by 800,000 kw., half of which should be transferred from East to West. In addition, 350,000 kw. of power will flow one way or the other according to the local load fluctuation, making the maximum power to be transmitted, 750,000 kw. This is equal to the total available power in the Rivers Hime, Takase, Sai, Atsusa, Tenryu, Ohi, and Fuji, and a part of the power from the Sagami River.

The transmission line distances from the principal rivers to the Western Zone terminating at Osaka City are as in Table V.

TABLE V

Names of Rivers	Power to be Transmitted	Distance in Miles
Hime and Kurobe....	220,000 kw.	230
Fuji and Ohi.........	300,000 kw.	220
Sagami.............	partial	260

Thus, future transmission line distances are considerably longer than at present.

The existing large transmission lines under operation are listed in Table VI.

The new transmission lines in the Western Zone average 40 miles longer than those of the Eastern Zone.

From the following figures, the logical transmission line voltage must be 220,000 volts in order to obtain the maximum benefit from the super-power system. Lines of this voltage are already successfully operated in America.

TABLE VI

Name of Company and Transmission Line	Distance in Miles
Eastern Zone	
Tokyo Electric Light Co. Inawashiro Line..................	140
Tokyo Electric Light Co. Joetsu Line......................	130
Kei-Hin Electric Power Co. Kohshu Line....................	125
Average Eastern Zone...........	132
Western Zone	
Daido Elec. Power Co. (sister Co. of the Toho Co.) Suhara-Osaka....................	150
Nippon Elec. Power Co. Sasatsu and Osaka................	190
Average Western Zone..........	170

The First Scheme Suitable to the Super-power System

The Toho Electric Power Co. has contemplated the first step of the system, and is preparing to organize a new company in co-operation with other leading power companies, to be called the "Dai-Nippon Soden Kabushiki Kaisha."

(*A*) *Amount of Available Power*

In a number of localities, part of the available power may be supplied for local demands, but the larger part must be transmitted to large load centers. This is shown in Table VII.

TABLE VII

Localities	Available Power in Kw.
Eastern Zone	
Wakamatsu..........................	250,000
Koriyama...........................	50,000
Shinano-Gawa.......................	150,000
Takasaki...........................	100,000
Hamamatsu..........................	100,000
Western Zone	
Nagoya.............................	300,000
Iida...............................	100,000
Gifu...............................	50,000
Total..........................	1,100,000

(*B*) *Auxiliary Steam Power Plants*

The auxiliary steam power plants will be built as follows:

Localities	Capacity in Kw.
Tokyo................................	50,000
Osaka-Kobe...........................	200,000
Taira................................	50,000
Total..........................	300,000

(*C*) *Main Step-down Substations*

The main step-down substations will be located in the vicinity of Tokyo, Yokohama, Nagoya, Kyoto, Osaka and Kobe, and near large cities which are far away from power plants

Transmission Lines

Frequency: 60 cycles
Transmission at 220,000 volts
Lines to be laid out as shown in Fig. 1

About 1,100,000 kw. of electric power from various rivers will be connected to the super-power system. A part of this will be supplied for the local demands, and approximately an even 1,000,000 kw. will be sent to large load centers at 220,000 volts. In order to supply 1,000,000 kw. of power at a load center all the year round, 300,000 kw. of auxiliary steam power plant will be required. (It is assumed that the stream flow decreases 25 per cent in the dry seasons and, in order to be on the safe side, 5 per cent is added, making the total decrease of the stream flow 30 per cent.)

The 1,000,000-kw., 220,000-volt transmission line system will be the first project of the super-power system. Its capacity will be increased to 3,500,000 kw. as the demand increases.

Frequency Problem

The benefits of the super-power system are numerous, as already stated. What can be shown by figures alone amounts to a saving of $50,000,000 or more per year. There are also many advantages which cannot easily be shown in dollars and cents. Furthermore, the above benefits and the economy of the super-power system can be obtained without great capital investment by avoiding the complications of non-unified systems and eliminating general waste.

The obstacle to this important work, the adoption and construction of the super-power system, is the frequency problem. Our electrical power industry was modeled after both the European and American systems, using 50 and 60 cycles respectively.

According to the investigation made by the Toho Electric Power Company, Ltd., the amounts of power generated at different frequencies at the end of June of each year are as in Table VIII.

TABLE VIII

Year	Kw. at 50 Cycles	Kw. at 60 Cycles	Kw. at Misc. Frequencies	Total
1913	117,000	137,000	60,000	314,000
1915	160,000	234,000	80,000	474,000
1917	290,000	297,000	104,000	691,000
1919	387,000	429,000	83,000	899,000
1921	504,000	708,000	194,000	1,316,000

Since June, 1921, the installation of the 60-cycle machines predominates over that of 50 cycles, and it may be said that at present the ratio of 50- to 60-cycle power plants is 2 to 3.

The existence of two different frequencies hinders the progress of the economical interconnection of different systems. Therefore, one standard frequency must be adopted for the super-power system in order to obtain the maximum benefits.

Although frequency unification offers the most promising solution to the problem, it is not favored by many because of the great expense expected. Unification at 60 cycles, however, proves upon careful study to be far more economical than the adoption of frequency changers, or any other method of making the system operate on various frequencies. The 60-cycle unification plan also meets all technical requirements. Machines for this frequency are cheaper than those built for 50 cycles. Economy and the successful realization of the super-power system, therefore, seem to depend upon the standardization of 60-cycle power throughout the country.

Method of Investigation

After the standard frequency plan has been adopted, thorough investigation work must be commenced immediately. This investigation should be of a practical nature to determine the extent to which changes in the existing machines and equipment are necessary for satisfactory operation at the new frequency. The most dependable way to arrive at a solution will be by actual electrical test.

One of the problems of the investigation work is the difficulty of obtaining power for testing electrical equipments, such as motors and transformers located at great distances from the power source. To overcome this the new frequency characteristics of this class of electrical equipment can be calculated from test data obtained under the old frequencies and the difficulty of making actual tests thus avoided.

When 60-cycle equipments are operated on 50 cycles, their electrical output decreases, while the safety factor of the rotating parts increases. On the other hand, when 50-cycle machines are operated on 60 cycles their electrical output increases, while the safety factor of rotating parts decreases. Therefore, in calculations and tests for 60-cycle operation, when rotating parts are operated at a speed higher than that for which they are designed, close investigation must be made as to the factor of safety.

Fortunately, machines that require testing are very few, for small motors and distribution transformers can be used with either frequency without any trouble, and large electrical equipments will be reconstructed. Installations that require testing are of medium sized machines. They can be tested or calculated as seems best, or a better plan would be to replace them with new machines of proper design.

Capital and the Proper Distribution of Expenses

With the unified frequency, the cost of electric energy will be less and the supply of power will be more reliable, both of which will benefit the customers. As electricity becomes a necessity of everyday life and is used by everybody, the expense of the frequency unification will be shared by the nation as a whole.

The capital for the unification must be obtained from the sale of bonds. Although the money market has been rather tight in the past few years, the capital necessary for unification is small, and, consequently, there will be no trouble in obtaining it.

Conclusion

We have discussed the future problem of the electrical industry in Japan with the object of realizing the super-power system. It will be the source of a cheap and reliable power supply. Although there are many ways to accomplish the same object, none of them have all the advantages of the super-power system. With complete frequency unification early realization of the System will be assured.

Two-kilowatt U. S. Coast Guard Radio Equipment

By I. F. Byrnes

Radio Engineering Department, General Electric Company

The public's first realization of the value of radio communication came as the result of those earlier instances in which this new agent made possible the rescue of imperilled lives at sea. Since that time, accelerated by the development of the vacuum tube, the interest in radio and new applications of it have increased at a phenomenal rate. Also, immense improvements have been made in transmitting distance, reliability, and other important factors. The following article which describes a recently developed ship transmitter clearly indicates how great has been the progress since the crude spark sets first gave birth to commercial radio.

—Editor.

The U. S. Coast Guard recently purchased three 2-kw. radio transmitting equipments[1] for service on its ice patrol vessels such as the S. S. *Tampa* and *Modoc*. These transmitters are an excellent example of the improvements that have been made in tube transmitter design during the past few years. As the radio art progresses, the performance requirements for modern tube transmitters become more and more rigid, especially with respect to the constancy and purity of the radiated wave.

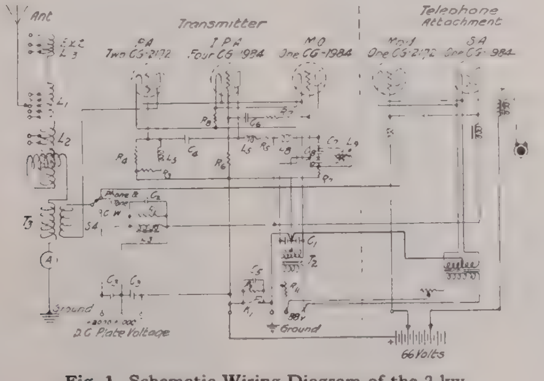

Fig. 1. Schematic Wiring Diagram of the 2-kw. Transmitter

The transmitter delivers an output of 2 kw. to the antenna over frequency ranges from 107 to 187 kilocycles (2800 to 1600 meters), and from 312 to 500 kilocycles (960 to 600 meters). The frequency is continuously variable within each range and it is possible to change from one transmitting frequency in each band to any other within the band in a few seconds. Moreover, settings can be made with an accuracy of better than 350 cycles or within 0.07 of one per cent, once the circuits have been properly calibrated. In other words, the operator can repeatedly set the dials for 500-kilocycle transmission, the most unfavorable condition, with the assurance that the heterodyned signal will be within audibility at the distant receiving station as long as the receiver remains unchanged.

It is of interest to consider the number of communication channels that may be obtained with the transmitter. On the basis of a 10-kilocycle spacing between transmitting frequencies, the transmitter can be calibrated for eight different frequencies in the 107- to 187-kilocycle band, and for 18 frequencies in the 312- to 500-kilocycle band. Those familiar with the design of earlier radio apparatus will appreciate the difficulties that were encountered in attempting to build a transmitter for more than six or eight transmitting frequencies.

Three forms of signalling are provided; viz., straight continuous wave, tone modulated telegraphy, and telephony. A separate

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(1) Identified by the trade designation as "Model T2."

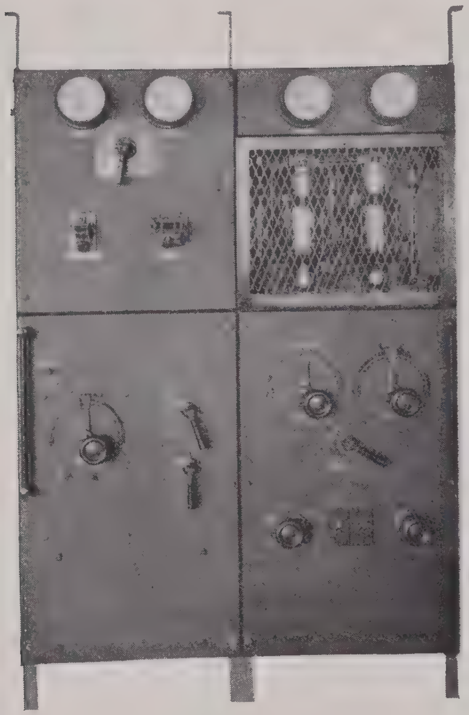


Fig. 2. Front View of the Transmitter

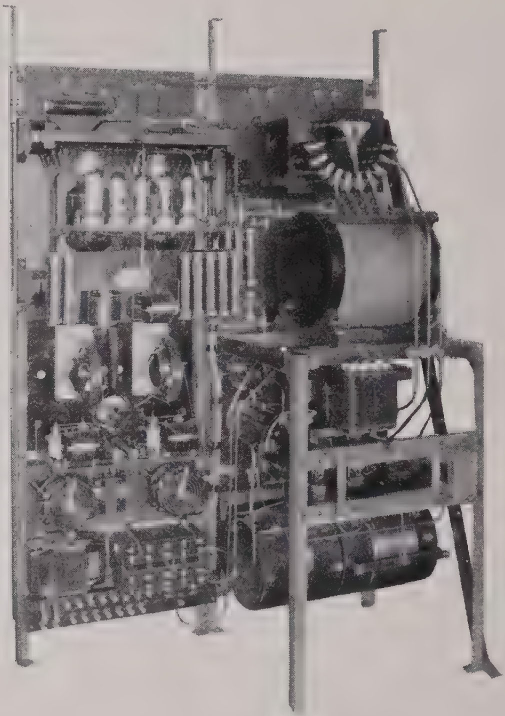


Fig. 3. Rear View of the Transmitter

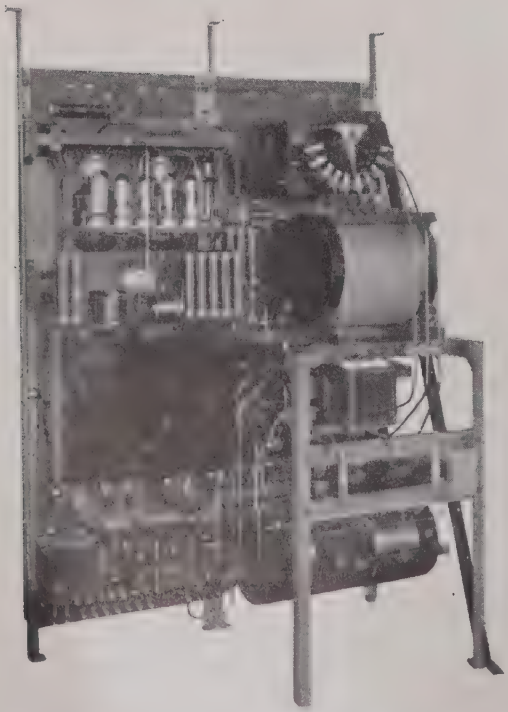
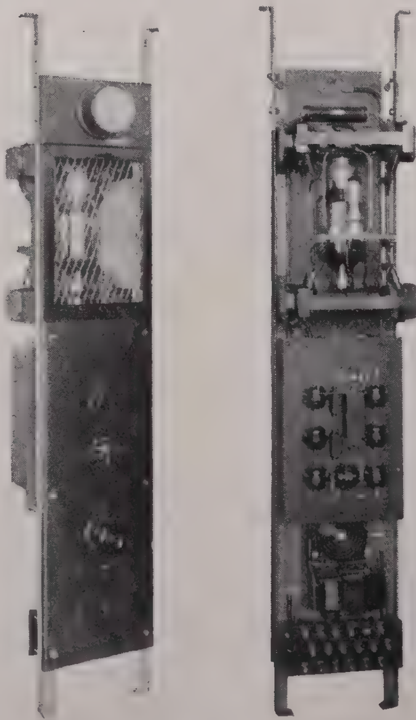


Fig. 4. Rear View of the Transmitter Showing the Shielding Box in Place Over the Master-oscillator Units



Figs. 5 and 6. Front and Rear Views of the Telephone Attachment telephone attachment is used for telephony and tone telegraphy. This attachment will be considered in detail later.

A new type of vacuum tube[2] was developed by the Research Laboratory in order to meet the requirements of the transmitter. This tube is rated at 1-kw. output on a plate supply of 2000 volts direct current. A thoriated filament is used, consuming 15.5 amp. at 11 volts. Prior to the development of this tube, the only 1-kw. tube available was one[3] which requires a plate potential of 10,000 to 15,000 volts direct current. An analysis indicated that a kenotron rectifier to supply this high direct-current voltage would be too bulky for shipboard service. In addition, the transmitter proper would be unduly large because of the high plate potential and its attendant insulation problems. The low voltage 1-kw. tube secures its plate supply from a simple two-unit motor-generator set that is installed in the engine room of the ship. The low plate voltage generator also appreciably increases the overall efficiency of the equipment, as otherwise the kenotron rectifier losses of 10 to 20 per cent would have to be supplied from an alternating-current motor-generator set whose efficiency would not exceed 60 or 65 per cent.

The transmitter proper uses a total of seven vacuum tubes operating in a master-oscillator power-amplifier circuit shown schematically in Fig. 1. A tube[4] normally rated at 50 watts output is used as the master oscillator. Four of these tubes operate in parallel as intermediate amplifiers and prevent reaction on the frequency determining circuits of the master oscillator. The two main power amplifier tubes[2] are connected in parallel and deliver power to the antenna through the antenna transformer.

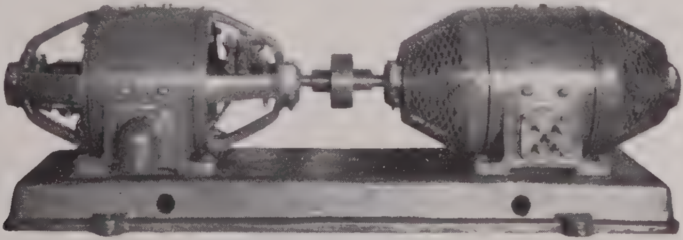


Fig. 7. Motor-generator for 2000-volt Plate Supply. Current for filament heating is derived from slip rings on the motor

The telephone attachment uses for a modulator one of the same type tubes[2] as is employed for main power amplification, and as a speech amplifier one of the tubes[4] such as is used for the master oscillator. On tone telegraphy, a specially designed alternator is connected in circuit in place of the microphone. This tone alternator has a frequency range from 400 to 800 cycles and weighs but one and one half pounds.

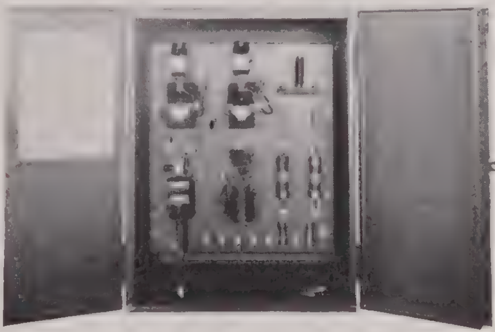


Fig. 8. Automatic Starter for the Motor-generator Shown in Fig. 7

The method of keying the transmitter may be understood by referring to the schematic diagram in Fig. 1. The contacts of the key relay are connected in series with the negative side of the plate supply. All grid leaks are returned to the negative plate supply. A resistor and condenser are connected in parallel with the key. When the contacts are opened, the plate current attempts to flow through the resistor which in turn places a large negative voltage on the grids of all the tubes. This action still further reduces the plate current with the result that a very small current through the resistor maintains the tube impedances at extremely high values, and no radiation takes place. Several kilowatts of direct-current power may be keyed in this manner with but slight sparking at the key contacts.

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[2] Model UV-851 or Navy Type CG-2172.

[3] Model UV-206.

[4] Model UV-211 or Navy Type CG-1984.

A front view of the transmitter is shown in Fig. 2. The panel is divided into four sections that contain all controls necessary for adjusting the frequency, power, and method of signalling. Four instruments are mounted across the top and indicate antenna current, plate current, plate voltage, and filament voltage. The lower right-hand panel contains two master oscillator variometers with vernier drive. Two variometers are used in order to secure a wide scale for the entire frequency band. The indicating pointers are provided with glass windows and a hair line is drawn between two small holes in each glass. This permits the pointers to be set very accurately to the divisions on the scale, or points may be "spotted" through the holes in the glass and the scale then engraved for the particular transmitting frequencies desired. The band-change switch simply selects the proper variometer for the desired frequency band.

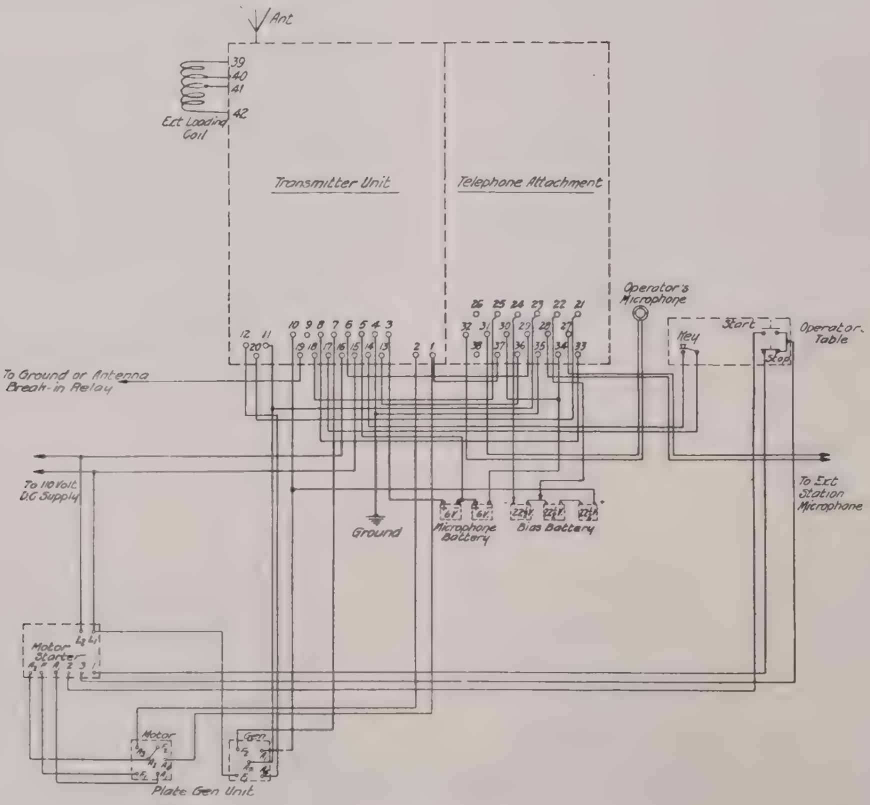

Fig. 9. External Connection Diagram

The rheostats at the lower section of the panel are used for controlling the plate voltage and filament voltage. The two push-button switches provide independent plate and filament voltage control.

The power-amplifier band-change switch selects the correct antenna transformer for either frequency band. The signal switch is a four-position device and provides low- and high-power continuous-wave signalling, telephony, and tone telegraphy. The antenna circuit is tuned by means of a ten-position antenna inductance switch and the antenna variometer. A small push-button switch at the left of the panel closes the magnetic key and permits convenient tuning. An overload relay is mounted to the left of the magnetic key and opens up the plate-generator field in case of excessive plate current.

Fig. 3 shows a rear view of the transmitter and the general assembly of the units. The two spherical variometers and the apparatus on the shelf directly below them comprise the master-oscillator circuit. All these units are carefully shielded by a doublelined box, shown in position in Fig. 4. The condensers above the terminal board in Fig. 3 are connected across the high-voltage commutators and act as effective filters, and also protect the machine from surges. All seven vacuum tubes are supported in a cradle suspended by springs and cushioned with sponge rubber. The large loading coil connected to the multi-point switch is used in the antenna circuit on the lower frequencies. A loading coil built for mounting on the bulkhead is also supplied and is used on the lowest frequencies. The two antenna transformers may be seen at the lower right-hand section of the transmitter.

The transmitter is assembled in such a manner that the rear section, containing the loading coil, resistors, condensers, etc., may be removed easily. This is necessary on account of the narrow doors and passageways that exist on many ships.

The telephone attachment is shown in Figs. 5 and 6. It is designed so that it may be installed adjacent to the transmitter where space permits, but if necessary it may be placed elsewhere in the radio room. For this reason a separate filament transformer and rheostat are provided on the attachment. A shield is also supplied to cover the audio-frequency units shown on the subpanel in Fig. 6.

Views of the plate motor-generator and its automatic starter are shown in Figs. 7 and 8. This machine runs at 2400 r.p.m., and the motor is supplied with slip rings that deliver 550 watts for filament heating. The generator is rated at 4.625 kw. at 2500 volts direct current, and is normally run at 2000 volts. Particular effort was directed by the designers of this machine to secure the smallest practicable dimensions with the result that the unit is but 62 in. long.

The external connections of the various units making up a complete equipment are shown in Fig. 9. The machine and its starting equipment are intended for installation in the engine room of the ship and are designed to operate successfully in the high ambient temperatures that exist in such places.

The U. S. Coast Guard Steamer *Tampa* Now on International Ice Patrol Duty, which Carries a 2-kw. Radio Set Such as Described in the Foregoing Article

Measurement of Internal Friction in a Revolving Deflected Shaft

By A. L. KIMBALL, JR.
RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

As previously reported in this magazine, the author has demonstrated that the internal friction in a revolving deflected shaft exerts a lateral displacing action which under certain conditions will be sufficient to cause the shaft to whip. Rings or hubs shrunk on the shaft oftentimes intensify this effect by introducing a rubbing friction between the shaft surface and the surface of the bore. To determine quantitatively the influence exerted by internal friction to produce whipping, the author has devised a special testing model with which he conducted the investigation described below. The article by Dr. Newkirk in this issue discusses a related phase of the subject.—EDITOR.

Introduction

In a previous article(1) the writer demonstrated how internal friction within a shaft might cause it to whirl, or to whip, under some conditions, illustrating the phenomenon by means of an experimental shaft. In connection with some tests on large turbo compressors, Dr. B. L. Newkirk, of this laboratory(2) concluded that the internal friction arising from the shrink fits of the impellers was a more active cause of shaft whirling than the frictional forces which might exist within the steel of the shaft itself. The purpose of this article is to set forth the results of an experimental test devised by the writer in order to obtain a quantitative measurement of this frictional force for the case of a shaft both with and without rings shrunk on it.

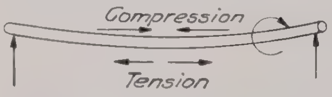

Fig. 1. Tension and Compression in Sagging Shaft

Nature of Internal Friction

When a horizontal shaft is supported at its two ends and sags downward in the middle due to gravitation, its upper fibers evidently are in compression and its lower ones are in tension (Fig. 1).

If the shaft is revolving, as shown by the arrow, every fiber must have its length alternately decreased and increased once every revolution, due to the alternating compression and tension to which the fiber is subjected. The amount of this alternating increase and decrease of length of the fibers depends upon how much the shaft sags and how far the fiber is from the center of the shaft. At the center of the shaft the change of length of the fibers is zero as they lie on the axis of the shaft. In all metals a frictional resistance to this change of length exists in a greater or less degree. When a fiber is shortening, a frictional compression is set up. When it is lengthening a frictional tension arises. These frictional stresses are very different from elastic stresses. The elastic stresses are proportional to the amount that the length of the fibers is changed, and have their maximum and minimum values at the bottom and top of the shaft. The frictional stresses arise during the change of length of the fibers; a frictional tension results when the length of the fibers is increasing and a frictional compression results when the length of the fibers is decreasing.

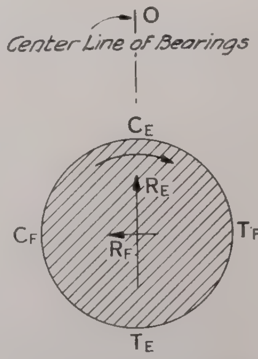

Fig. 2. Cross-section of Shaft Showing Elastic and Frictional Reactions

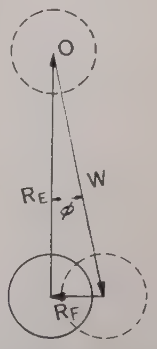

Fig. 3. Sideways Deflection Produced by Frictional Reaction

Fig. 2 shows a cross-section of the shaft near its middle point. All of the fibers in the upper half are in elastic compression, C_E, and those in the lower half are in elastic tension T_E. When the shaft is rotating in the direction shown by the arrow, all the fibers in the right hand half are *increasing* in length, resulting in a frictional tension T_F and the fibers in the left half of the shaft are decreasing in length, producing a frictional compression C_F. The elastic stresses produce an upward reaction against gravity indicated by R_E in the figure, whose direction is from the elastic tension toward the elastic compression side of the shaft. So also the frictional stresses produce a corresponding transverse reaction R_F. The magnitude of R_F is far smaller than that of R_E, however. While the elastic reaction R_E is balanced by gravitation, the frictional reaction is unbalanced until the center of gravity of the shaft swings sideways as shown in Fig. 3.

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(1) A. L. Kimball, Internal Friction Theory of Shaft Whirling, G. E. REVIEW, April, 1924, p. 244.

(2) B. L. Newkirk, Shaft Whipping, G. E. REVIEW, March, 1924, p. 169.

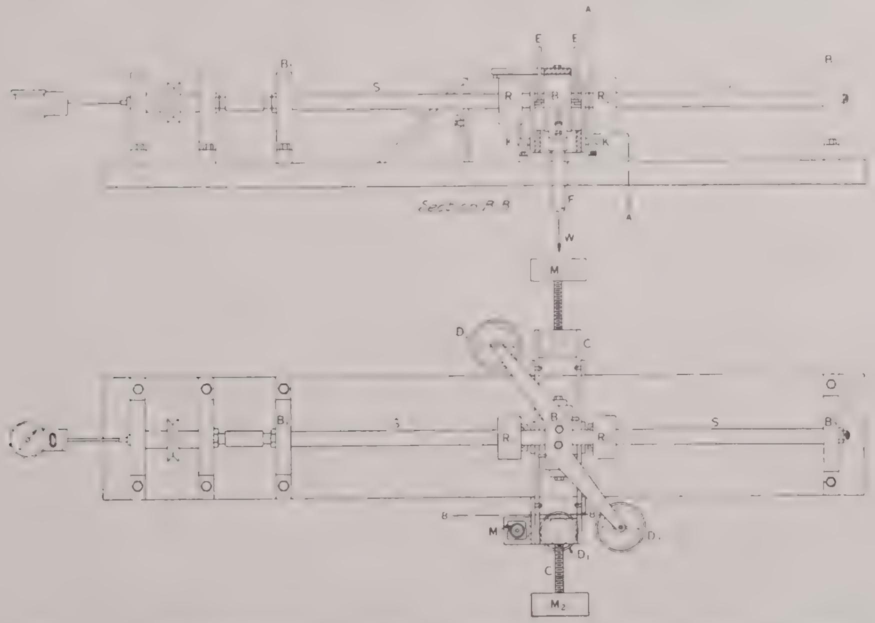

Fig. 4. Plan and Side Elevation of Apparatus for Measurement of Internal Friction in a Shaft

Then the gravitational force W balances the resultant of the two components R_E and R_F. It is seen that a knowledge of the angle Φ gives a direct comparison between the frictional reaction R_F and the elastic reaction R_E. It is also to be noticed that the angular deflection of the shaft (Φ) is measured in the same direction as that of shaft rotation. If the shaft is placed on end so that the disturbing force R_F is not balanced by gravity, a whirling motion of the shaft is likely to build up provided the rotational speed *exceeds* the natural whirling speed. This point is discussed at some length in an article previously referred to⁽¹⁾.

In the preceding discussion the frictional reaction R_F has been shown to arise from frictional resistance in the fibers themselves during compression and elongation. This is not the only sort of friction which may cause the reaction R_F, however.

Any frictional resistance which arises within a revolving deflected rotor, while one-half of the cross section is stretching and the other half is shortening, also must produce a frictional reaction component R_F (Fig. 3). For example, the rotor may be a shaft with rings shrunk on it. In this case, friction may take place between the surface of the shaft and the inner surface of the rings, due to a working of the shaft in the rings as it revolves. The surface fibers of the deflected shaft go through a cycle of elastic lengthening and shortening for every complete revolution of the shaft. This produces a friction against the inside surface of the rings which may be so great as to cause the shaft to take a slight permanent set when deflected a small amount.

Method of Measurement of Friction Reaction

When once the transverse reaction, due to internal friction in a revolving deflected rotor, is clearly perceived, a possible way of measuring this reaction (R_F, Fig. 3) suggests itself. This may be done by obtaining a measurement of the angle Φ, and thus getting a comparison between the frictional reaction R_F and the downward gravitational force W. As the angle Φ is very small, special precautions must be taken to obtain reliable measurements.

Drawings of the apparatus are shown in Figs. 4 and 5, and a photograph in Fig. 6.

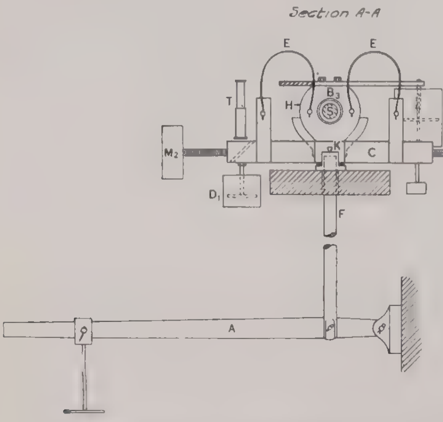

Fig. 5. End Elevation of Apparatus Shown in Fig. 4

The shaft S, of commercial carbon steel, ⅞ in. diameter and 36 in. long, was mounted on ball bearings B_1 and B_2. The downward force W was applied to the middle of the shaft through the ball bearing B_3 and rod which was attached to the weight arm A.

In order to determine the angle Φ, the sideways deflection of the center of the shaft from the vertical, arising during rotation, was measured while the shaft was given a downward deflection by means of a suitable weight on the weight arm. Instead of directly observing the sideways deflection of the shaft itself, the angular deflection of a cross arm of considerable inertia was measured. This was done by observing through a telescope the motion of the image of a fixed scale in the mirror M carried by the cross arm. The scale was calibrated in mils sideways deflection of the shaft, both by calculation and by direct comparison with cathetometer measurements.

The motion of the shaft was communicated to the cross arm by the sideways motion of the housing H to which the cross arm was connected through the flexible springs E. The cross arm carried the adjustable weights M_1 and M_2, giving it the required inertia and by which it was carefully balanced upon the knife edge K. By this means high frequency vibrations and tremors were largely eliminated and a steady deflection was obtained which could easily be observed.

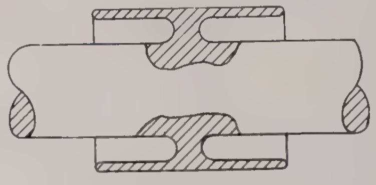

Fig. 7. Flange Machined on the Shaft to Support Ball Bearing

It was found that, although the balanced cross arm and spring connection eliminated small high frequency vibrations, a low period swing remained which made observation difficult. Therefore, the damping cup, D, was built in which a heavy oil was placed and a plunger, affixed to the balanced cross arm A, worked up and down in the oil when the cross arm swung. Also, a special pair of damping cups D_2 was used to restrain the transverse resonant vibration or critical speed vibration of the shaft while passing through this speed.

With this arrangement, satisfactory measurements of the transverse deflection of the shaft could be obtained.

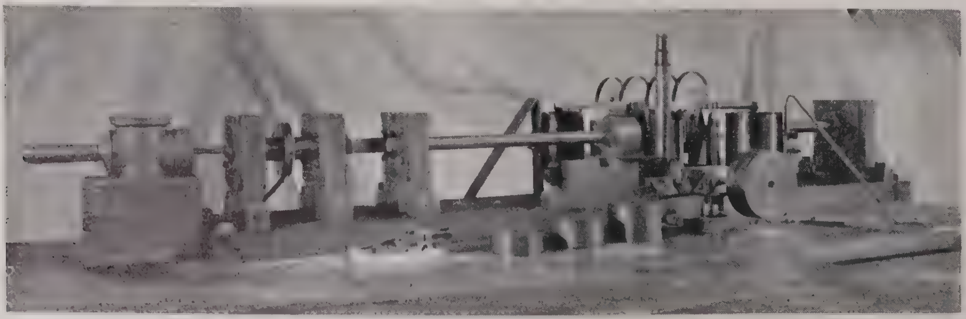

Fig. 6. Apparatus for Internal Friction Tests

Since the internal friction in the shaft is small, precautions had to be taken to eliminate all extraneous frictional effects. If the inner race of the ball bearing B_3 or any bushings were mounted directly on the shaft, an error would be likely to result from the working of the shaft in these rings. In order to overcome this effect a special flange was machined on the shaft of the form shown in Fig. 7, the inner race of the ball bearing B_3 being mounted on this flange. The frictional action in this contact surface was a negligible quantity.

Results of the Tests

Fig. 8 shows curves of the sideways deflection obtained by this apparatus due to the internal friction in the steel shaft itself. One of the curves shows the deflection in mils and the other the torque necessary to produce this deflection. The torque gives a direct measure of the frictional force, being proportional to it. Its curve rises more rapidly than the deflection curve, with increase of load, because the torque is proportional to the load multiplied by the sideways deflection.

Fig. 9 shows deflections plotted against speed for several shaft loads. It is a remarkable fact that the internal friction is nearly independent of the speed of rotation, contrary to the very common assumption that internal friction in metals is proportional to velocity of strain, like fluid friction. If this were true, the deflections would have to increase as the speed of rotation increased.

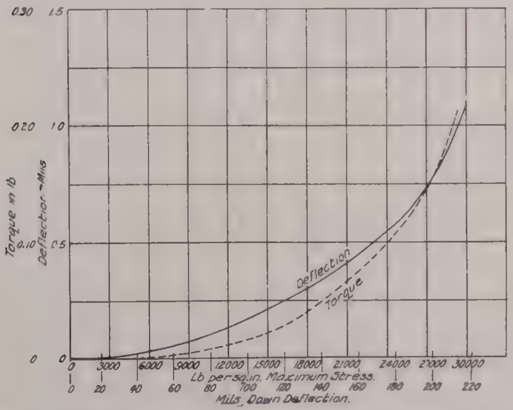

Fig. 8. Curves of Sideways Deflection Due to Internal Friction Within the Shaft for a Speed of 1000 r.p.m. and Varied Load

Having found the magnitude of the internal frictional reaction, it was then possible to find how much this frictional reaction was increased by shrinking rings on the shaft. Three pairs of steel rings and three pairs of brass rings were chosen whose dimensions and shrink fits are given in Table I.

The shrink fits were measured by a Johannsen gauge and Starrett micrometer. Through an error in machining, the fit of the left-hand ring was looser than intended. The results of these tests are shown in the deflection curves of Figs. 10 to 14.

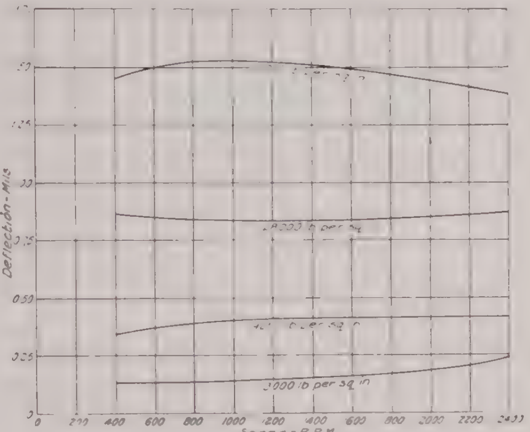

Fig. 9. Deflections Plotted Against Speed for Several Shaft Loads

The curve plotted below the zero line is taken from Fig. 9 and shows the deflection alone due to the internal friction in the shaft. By means of this curve it can be seen at a glance how much greater deflections are produced by the shaft carrying the rings than without them. The deflections above the zero line represent the increased deflection due to shrinking the rings on the shaft. Therefore, to obtain the measured

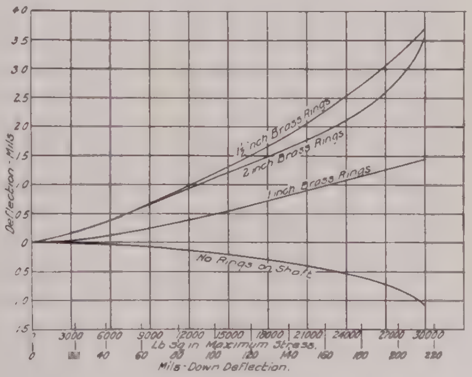

Fig. 10. Deflection Produced by Brass Rings Shrunk on the Shaft for a Speed of 1000 r.p.m.

deflections for the shaft carrying rings, the distance between the upper and lower curves must be measured rather than the distance from the zero line. First, a pair of brass rings—1 inch in thickness—was shrunk on the shaft as shown in Figs. 4 and 6 (R_1 and R_2). Next, a series of measurements was taken with the pair of 1½-in. brass rings shrunk on the shaft, then with the 2-in. pair, and then for the three pairs of steel rings. These measurements made up a series of six runs which were carried out in each case for various loads on the shaft and at various speeds. Figs. 10 and 11 show the results for the brass rings, the first set of curves giving the deflections in mils plotted against the load on the shaft, and the set of curves of Fig. 11 showing the deflections for a given load of 149.5 lb. for various speeds. Figs. 12 and 13 show the same factors for the three pairs of steel rings.

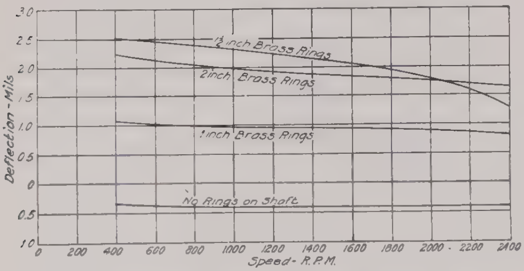

Fig. 11. Deflection Produced by Brass Rings, Plotted Against Speed for a Load of 149.5 lb.

TABLE I

Material and Position	Outside Diameter	Breadth	Shrink Fit
Steel—Right..	3 in.	1 in.	0.0013 in.
Steel—Left...	3 in.	1 in.	0.0002 in.
Steel—Right..	3 in.	1.5 in.	0.0011 in.
Steel—Left...	3 in.	1.5 in.	0.0003 in.
Steel—Right..	3 in.	2 in.	0.0010 in.
Steel—Left...	3 in.	2 in.	0.0001 in.
Brass—Right.	3 in.	1 in.	0.0012 in.
Brass—Left...	3 in.	1 in.	0.0002 in.
Brass—Right.	3 in.	1.5 in.	0.0012 in.
Brass—Left...	3 in.	1.5 in.	0.0002 in.
Brass—Right.	3 in.	2 in.	0.0011 in.
Brass—Left...	3 in.	2 in.	0.0003 in.

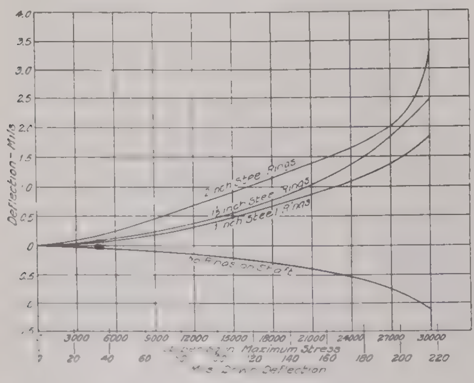

Fig. 12. Deflection Produced by Steel Rings Shrunk on the Shaft for a Speed of 1000 r.p.m.

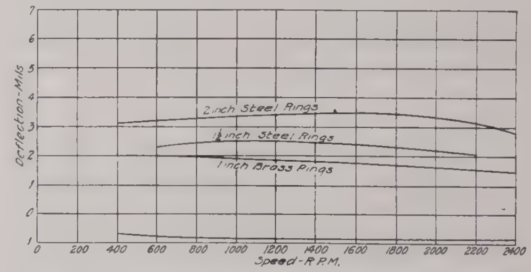

Fig. 13. Deflection Produced by Steel Rings, Plotted Against Speed for a Load of 149.5 lb.

Discussion of Results

The results obtained confirm the conclusion, arrived at by Dr. Newkirk from tests, that the frictional effect of shrink fits may be a more active cause of shaft whirling than the internal friction within the shaft itself. They show that, even with the rather small shrinkages used in the tests and with the particular shaft used, the effect of internal friction may be increased from two to five fold. The effect produced by brass rings did not differ very much from that produced by steel ones. These deflections correspond to a torque running up to 0.8 inch-pound (Fig. 14), which may give so small a shaft as this a considerable tendency to whirl under the right conditions.

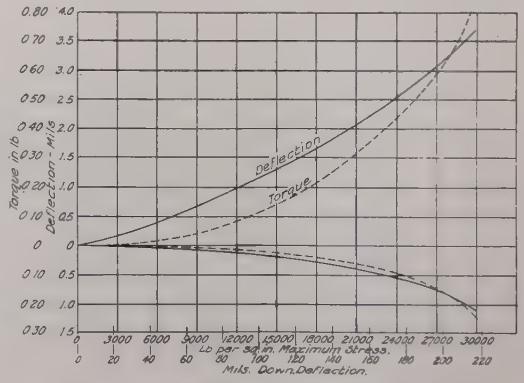

Fig. 14. Deflection and Corresponding Torque for 1½-in. Brass Ring Shrunk on the Shaft

In closing, the writer wishes to express his acknowledgment to Mr. E. H. Hull for assistance in carrying through the tests.

Shaft Whipping Due to Oil Action in Journal Bearings

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Shaft whipping is a form of vibration or whirling developed under certain conditions in shafts running above their critical speeds. The authors have produced this phenomenon with models, and have traced the cause to the action of the oil film in the bearings. They find that the phenomenon when produced in this way does not occur at running speeds lower than about double the critical speed of the rotor. To prevent trouble from this source the authors suggest that very low unit bearing pressures be avoided or that a friction-damped spring be used. A previous investigation reported in this magazine dealt with a similar phenomenon caused by internal friction of the rotor. The article by A. L. Kimball in this issue details the measurement of the internal friction of shafts, which also has been found to be a cause of whipping.—Editor.

Introduction

A previous article⁽¹⁾ described an investigation of a troublesome form of shaft vibration or whirling termed shaft whipping, which, it was found, was supported by the cramping action of long sleeves or hubs on the shafts of rotors running above critical speed. In the present article an account will be given of later tests which showed that whipping of much the same nature is caused, under certain conditions, by the action of oil in journal bearings.

Nature of Whipping

Whipping in general may be defined as resonant vibration or whirling⁽²⁾ of the shaft of a machine when running at other than the resonant or critical speed. The vibrations encountered at the critical speed are synchronous with the revolutions, and are caused by the deflecting forces due to unbalance; also, under ordinary conditions, vibrations of this nature reach a maximum at the critical speed and outside of a narrow range of speed disappear almost entirely. Whipping, however, has been found to occur over wide ranges of speed, the vibration or whirling frequency bearing little if any relation to the number of revolutions per minute, and the phenomenon is practically independent of balance.

Whipping Due to Cramping Fits

In the case of the whipping caused by the cramping action of long fits on a shaft, the whipping did not occur at speeds below the critical speed, but it did develop at any higher speed. The motion was found to be an elliptical or circular whirl of the shaft in the same direction as the rotation, with a frequency about equal to the critical speed. This action did not usually develop of itself, but required a jar, or other stimulus which would deflect the shaft, to start it. Quantitative tests carried out with small but nicely built models running in ball bearings demonstrated that whipping of this nature was rendered much more difficult to produce—i.e., less likely to develop—by reducing the length of the fits or by making them tighter (as by increasing shrink or press fit allowances); but that it was possible to cause whipping even with very short, tight fits by extreme shock, causing a large deflection of the shaft. Without an extreme stimulus to start the whipping, however, these models would run at any speed, up to 10,000 r.p.m.—the highest speed studied—without appreciable vibration of any kind save that occurring at critical speed (about 1950 r.p.m.) when the models were thrown out of balance. A remedy for the commercial machines showing a tendency to whip was found in the use of spring-supported bearings with frictional damping imposed. An attempt to stop the whipping in one case by correcting the only recognized source of the trouble—i.e., by shortening the fits on the shaft—was unsuccessful. This in itself aroused a suspicion that there was another source of whipping; but in the absence of quantitative data on fits, such a conclusion was not considered established at that time. Furthermore, the spring bearings were entirely successful, not in concealing the whipping, but in stopping it altogether.

Indication of a New Source of Whipping

In the light of these results, two models were built, for study of shaft behavior in the critical speed range, with short and extremely tight fitting wheel hubs which we felt sure could cause no whipping unless the shaft was given a dangerous deflection while running; —and the possibility of this was prevented

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⁽¹⁾ Shaft Whipping, by Dr. B. L. Newkirk, General Electric Review, March 1924, p. 169.

⁽²⁾ Whirling is viewed as a composite of two vibrations in planes 90 deg. apart and with a phase difference of one-quarter period.

by the use of a guard ring, with limited clearance over the shaft. The rotors of these models weighed 400 lb. each, and ran in journal bearings. They came fully up to expectation as to behavior at critical speed; but they regularly developed pronounced whipping when the speed was carried higher than about twice critical speed.

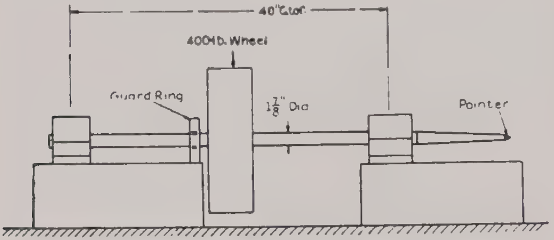


Fig. 1. Model Used in the Study of Shaft Whipping

The set-up of the models is indicated in Fig. 1. The rotor, known as Model IX, consisted of a 1⅞-in. shaft carrying a 400-lb. wheel, running in two journal bearings 40 in. apart, center to center. The bearings were of usual oil-cooled design, 1⅞ by 2½ in. with a 0.003 to 0.004-in. clearance (difference of diameters) over the journal. A pointer, shown in the figure as a tapered extension of the shaft, was attached at one end and the point ground to run truly, so that any vibration or whirling of the shaft produced a corresponding motion of the tip of the pointer which could be observed conveniently in strong light with a low power microscope. The critical speed of this model was about 1210 r.p.m., the pointer indicating an elliptical whirling at this speed, of amplitude approximately proportional to the degree of unbalance of the model.

The whipping showed itself as a similar whirling of the shaft when the speed rose above 2300 r.p.m. Motion pictures were taken of this pointer, the exposures being timed so as to catch a complete whirl on each picture. Some samples from these records are shown in Fig. 2, from which it can be seen that the motion was an *open whirl*. By means of an oscillograph and magnetic "exploring coils" it was determined that the rate of whirling was 1205 to 1280 per minute (very nearly the critical speed frequency), at speeds from 2300 to 5000 r.p.m;—also that the whirling took the same direction as the rotation of the shaft.

Tests to Determine the Cause of the Whipping

From the start, the journal bearings were suspected of being responsible for the whipping. Indeed, there was little else in the model to suspect. The wheel fit was so tight that the whipping could hardly be due to "working" of the fit. Three factors apart from the journal bearings, however, were tested as possible sources of the trouble: (1) the belt drive; (2) the degree of unbalance; and (3) the thrust-collars on the shaft. The tests eliminated these possibilities. The model whipped when coasting with the belt removed just as it did when running steadily or accelerating with the belt on. The balance was refined until the model could be run at critical speed with less than half a mil vibration at the middle of the shaft, and still it whipped very much as it had when considerably out of balance. The thrust collars were backed off and the rotor held in position by blocks of soft carbon clamped at the ends of the shaft, but this had no noticeable effect on the whipping.

The first positive indication of the cause of this phenomenon was the accidental discovery that the whipping was stopped immediately *by shutting off the oil* supply to the bearings, and could be brought back to full amplitude promptly by turning the oil on again.

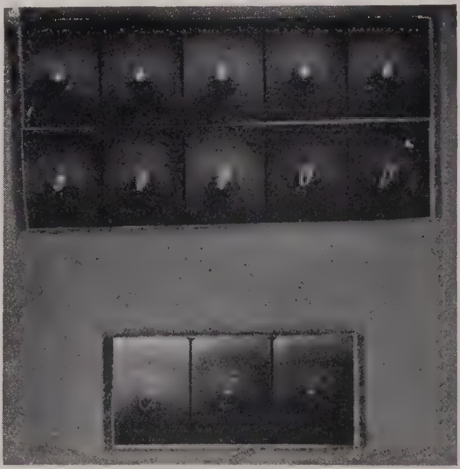
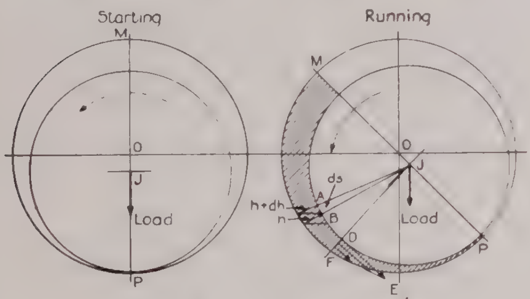


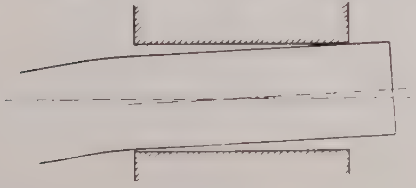
Fig. 2. Motion Picture Records of Whipping of Model IX, Due to Oil Action

Top: Building up of whip at 3000 r.p.m.—good balance
Bottom: Double exposure whirl centered about steady position

The use of one friction-damped spring bearing was found also to stop the whipping. The friction was essential, however, as it was found that a special spring bearing designed so as to avoid inherent damping permitted violent whipping.

The solid sleeve bearings first used with this model were rebabbitted several times in the course of tests on vibration at critical speed. In every set-up, however, the whipping developed, this indicating that the phenomenon was not due to accidental irregularities in the bearing lining. Another model rotor, No. XI, was also available, which ran in the same bearings. It had a stiffer shaft and a critical speed of about 1950 r.p.m., but was otherwise similar to Model IX. When run at 3600 r.p.m. or faster, this model developed whipping very similar in character to that of Model IX. This served to indicate that the whipping could not be considered due to accidental peculiarities of Model IX.





Figs. 3 and 4. Displacement of Journal in Bearing by Oil Action

Fig. 5. Diagonal Position of Journal in Bearing in Well Developed Whipping

It had been thought that the whipping might be due in part to misalignment of bearings. This point was difficult to test with the older sleeve bearings, but was settled by the use of a new set of self-aligning bearings with spherical seats. It was found that intentional misalignment to any marked degree *prevented the whipping*, but that when the ball seated bearings were permitted to align themselves the models whipped quite as violently as they had when running in the sleeve bearings.

These results indicated that some action of the oil in the journal bearings was responsible for the whipping and in consequence we have called it the "Oil Whip," to distinguish it from whipping due to cramping fits.

Theory of Oil Action Causing Whipping

It is a familiar fact, established by the experiments of Tower, that in a well lubricated journal bearing carrying load the journal is displaced somewhat from the bottom of the bearing, as is indicated in Figs. 3 and 4. The action is as follows: Oil clings to the rotating journal, and is carried along with it; at points around the bearings where the clearance is diminishing, oil is crowded in and builds up a considerable pressure (indicated by shading on the diagram); on the other side of the bearing, where the clearance is increasing, the oil pressure is very low. This results in a net difference of pressure which moves the journal forward, so that its center *J* takes up a position relative to the bearing center *O*, somewhat as shown.

It seemed that the "Oil Whip" might be due to this kind of action in the oil film, the journal center not finding a position of rest, as at *J*, but moving around the bearing center *O*, propelled by a pressure zone behind the point of nearest approach, *P*. It was recognized, however, that the action of the fully developed whip was more complicated than this, because the amplitude was so great as to cause the journal to take a diagonal position along the length of the bearing, as indicated in Fig. 5. But it was thought that substantially the same action took place at the ends of the bearing, with the pressure zones diagonally opposite at the two ends.

This theory would explain how the oil film can produce a whirling motion of a journal, and also account for the fact that the observed whipping took the same direction as the rotation. As given, however, it does not explain why the whipping was confined to a speed range above about twice critical speed. Further tests were therefore made to obtain additional information on the nature of the oil action.

Confirmation and Extension of Theory by Tests with Special Model. Description of Model XIIA

A simpler model was built for further study of the oil whip. In order to avoid dealing with two journal bearings either or both of which might be involved in the whipping, the new model was equipped with only one journal bearing, and one ball bearing. For further simplification and symmetry, the model was arranged to run with the shaft vertical, so that there was no static load on the journal bearings. Finally, for ease of manipulation, the model was made quite small, and with a low critical speed (800 r.p.m.). The set-up was made as shown in Fig. 6. The weight of the rotor, about 50 lb., was carried at the top by the self-aligning ball bearing. Four 1½ in. by 2 in. interchangeable journal bearings were provided, which were duplicates except for the clearance over the journal. The ball seats were carefully fitted. The bearings were each made in one piece and bushed with brass. Oil was fed in at the middle under pressure, distributed by a single lengthwise groove, and allowed to escape from the ends of the bearing.

Behavior of Model with Shaft Vertical

Fig. 7 indicates in a descriptive way the behavior of the new model when set with the shaft vertical, representing a run with a large clearance in the journal bearing. The critical speed vibrations are shown as a small peak in the curve at about 800 r.p.m. A much larger peak of vibration was found at 1520 r.p.m., a little less than double the critical speed. Whipping started at 2250 r.p.m., growing more violent with further increase of speed. It was noted at this time that the quantity of oil discharged from the ends of the bearing was greatly increased when whipping developed. These results were obtained with the journal bearing properly aligned, but restrained by the pinch of the ball seat. When this restraint was removed by loosening the bearing cap bolts, the model would not whip, but developed the same two peaks of vibration—one at critical speed, and one at about twice critical speed. Moderate restraint of the bearing resulted in moderate whipping, accompanied by some motion of the bearing on its ball seat.

Close observation of the journal and journal bearing revealed two phenomena which confirmed the theory of the oil action and led to an extension of it which explained the peak of vibration at double critical speed, and made possible a more satisfactory explanation of the whipping. The first was found with the model running at low speed, 200 to 300 r.p.m., with a large clearance (0.008 in.) in the journal bearing and plentiful oil supply. The journal took up a whirling motion in its clearance, traveling slowly around in the same direction as the rotation—according to the simple theory of oil action in bearings. This was not whipping. The shaft did not bend, but tilted around like a conical pendulum, pivoting at the top on the self-aligning ball bearing. The motion was slow and easily followed by the eye. It occurred regardless of whether the ball seat of the journal bearing was restrained or not. But it died out or failed to develop when the oil supply was shut off. This "journal whirl" was found to continue to higher speeds and then appeared to be faster, though not nearly so fast as the revolutions. It was found that the frequency of this journal whirl was very nearly one-half the shaft r.p.m.; i.e., the journal made one circuit of the bearing in approximately two revolutions. This was sufficient to explain the peak of vibration at about twice critical speed; for the frequency of the journal whirl would then correspond to the natural vibration frequency of the shaft, and the shaft would be expected to respond in resonance to this stimulus. This peak was therefore named the "Oil Resonance" peak.(3)

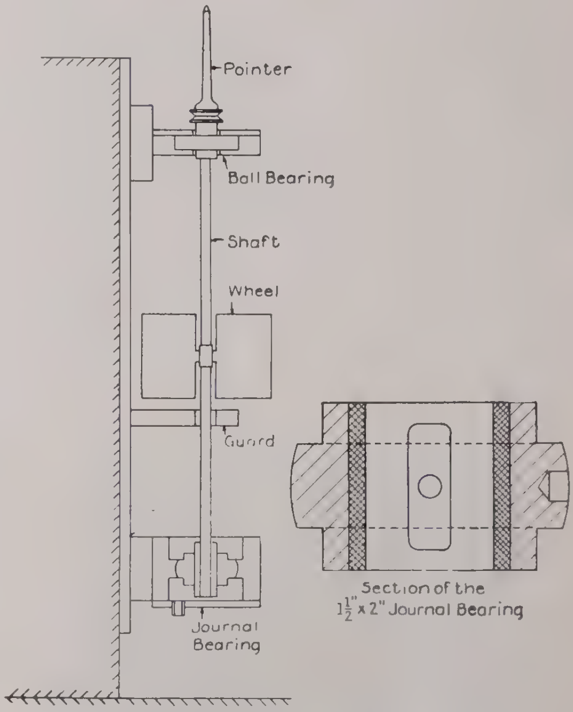


Fig. 6. Model XIIA Set with Shaft Vertica

Another phenomenon was found when running at speeds higher than the oil resonance speed with the journal bearing free to tilt. It will be remembered that no whipping developed under these conditions. The journal bearing, however, took up a wabbling motion which was found to be another case of conical whirling, but with the ball seat as pivot. The amplitude was small, and the frequency rather high, so that direct observation was more difficult than in the case of the journal whirl. A small post attached to the bearing and projecting up parallel with the shaft served to magnify the motion. It was now plainly seen that the direction of the whirl was forward—with the revolutions—and oscillograms were taken which showed that this frequency also was equal approximately to one-half the r.p.m. This "bearing whirl" stopped when the oil supply was shut off, and also if the bearing cap were drawn tight. With plenty of oil and a tight bearing cap, whipping developed if the speed exceeded 2250 r.p.m.; below this speed and above the oil resonance, both shaft and bearing were quiet. If, in this range, however, the bearing cap were drawn up very gradually, the bearing motion continued for a time and a critical adjustment was found in which the shaft responded in resonant vibration. It seemed that a slight restraint of the bearing imposed some friction on its tilting motion and retarded its frequency; and that in the critical adjustment the frequency had been reduced to the resonant value.

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(3) It is a fact, though perhaps not generally recognized, that a rotating shaft will respond in resonant vibration to a suitable stimulus in practically the same manner as though it were not rotating. Thus the rotation and the resonant vibration are superposed without mutual interference. Similar resonance peaks at other speeds have been found in operating very sensitive models, due to eccentric tachometer pulleys and even to resonance with the rotation of the ball cage in ball bearings.

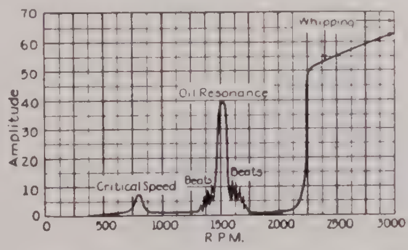

Fig. 7. Behavior of Model XIIA Set as Shown in Fig. 6

The effect of friction on the journal whirl was then investigated, and it was found that its frequency also was reduced quite appreciably by even such slight friction as that of a dial indicator bearing on the shaft.

Extension of the Theory of Oil Action

These discoveries led to an extension of the theory of oil action. Referring to Fig. 4, consider the distribution of velocity in the oil film. The layer next to the journal has the full journal velocity, as represented by the arrow *DE*. The outside layer, next to the stationary bearing surface, has zero velocity (point *F*.) In the intervening space, the oil velocity is somewhere between these extremes, and the simplest estimate would consider the distribution of velocity represented by a straight line, *EF*, through the tips of the arrows. The average oil velocity, then, across any radial section of the clearance, should be about half the surface speed of the journal. The rate of oil flow past any radial section should be proportional to the local clearance; much less oil, then, can pass the point of nearest approach, *P*, than is carried past the opposite side at *M*, where the oil space is widest. Assuming plentiful oil supply, this means that oil is pumped into the shaded space faster than it can escape circumferentially past the point *P*, and that a considerable pressure will be built up and the excess oil squeezed out axially, unless the journal or the bearing yields to this impulse and moves around, opening up space for the oil as fast as it is required. The rapidity of such motion may be estimated as follows:

Let

h = radial clearance at any section, say at *B* on the shaded side of the bearing;

$h+dh$ = radial clearance at section *A*, a small distance, *ds*, toward *M* from *B*.

Now, while the journal revolves through the distance *ds* from *A* to *B*, a volume of oil equal to $\frac{h}{2}\,ds$ is carried past *B* (assuming unit width of oil film, perpendicular to the paper), while at the same time a volume equal to $\frac{h+dh}{2}\,ds$ moves past section *A*, bringing an excess of oil equal to $\frac{dh}{2}\,ds$ to section *B*. This excess oil can be accommodated if the clearance at *B* is increased by the amount $\frac{dh}{2}$. Now if the journal as a whole revolves around the bearing center *O* through an angle equal to *AJB*, the clearance at *B* will increase, becoming equal to $h+dh$, the clearance at *A* previous to this motion. Hence, if the clearance at *A* is to increase to $\frac{h+dh}{2}$, the journal must revolve about *O* about half as far, or through half the angle *AJB*. It will be seen that this or a similar analysis would hold at any point around the bearing; and that, in general, space will be adjusted to the local oil supply if the journal center *J* moves around *O* with about one-half the angular velocity of shaft rotation, or if the journal runs steadily, and the bearing yields to the oil at the same speed.

It may be concluded further that, if friction is present to resist the journal or bearing motion; i.e., if considerable work is required of the oil action, the oil pressure required will be higher, resulting in additional end leakage and a reduced frequency. The latter has been illustrated with the bearing whirl and journal whirl and an increased end leakage of oil noted when the model whipped violently.

In the horizontal setting, the oil resonance peak was not observed, for it apparently merged with the whipping. The journal whirl, however, developed very much as it did when the shaft was vertical. The bearing, no longer being free of restraint, failed to develop the whirling motion, but moved more or less irregularly on its spherical seat when the cap was loose.

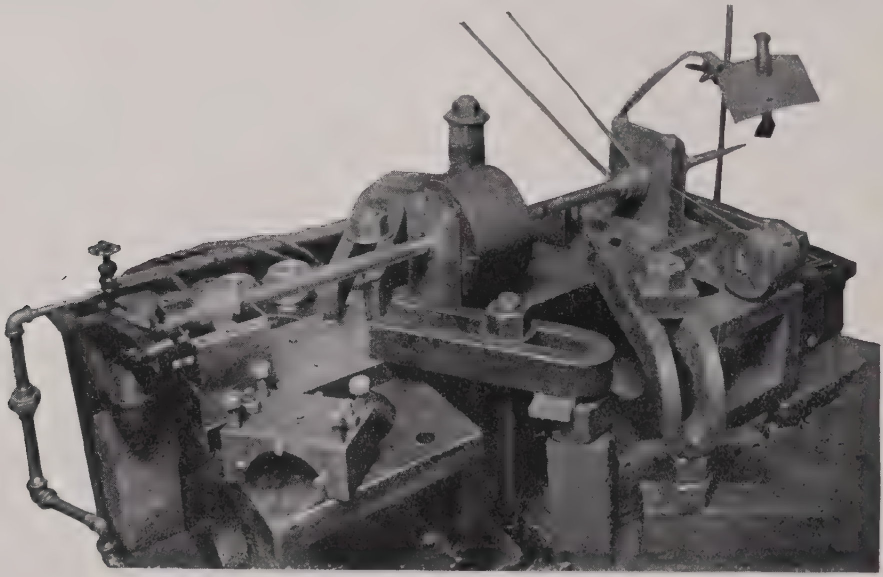

Fig. 8. Model XIIC Set With Shaft Horizontal

Explanation of the Oil Whip

These considerations led to the conclusion that the oil whip was due to the type of oil action that has been described. It seems that this oil action may occur at speeds below the oil resonance speed (about twice critical speed) but that its frequency is then too low to produce resonant vibration or whipping of the shaft. At the oil resonance, the shaft responds to its natural frequency and, as the speed is increased still further, one might expect the frequency of the oil action to increase, the resonance to be lost, and the shaft to run quietly at all higher speeds. This actually occurred with Model XIIA set vertically with the bearing cap loose. But with the model horizontal, the resonant vibration continued from the oil resonance to all higher speeds. That is, the shaft failed to "pull through" the oil resonance. The reason seems to be that the oil action is reduced in frequency when it meets with frictional resistance. The maintenance of whirling vibration requires the overcoming of frictional resistance, which probably

Behavior of Model XIIA with Shaft Horizontal

The model was set horizontally, with no other change, as in Fig. 8. Two differences in its whipping behavior were then noted: (1) whipping started not at 2250 r.p.m. but at the oil resonance speed of 1520, continuing to all higher speeds; and (2) whipping persisted even with the bearing cap loose, though it appeared less vigorous than with the cap tight. It had been noted when the shaft was vertical that partial restraint of the bearing had caused moderate whipping. Therefore, since the bearing carried load in the horizontal setting it was subject to partial restraint even with the cap loose and it was not surprising that the model whipped. The discrepancy between the starting points of whipping in the vertical and horizontal positions was thought to be due to the damping effect of the end thrust on the ball-bearing in the vertical position, as explained on page 565.

increases sharply with the amplitude on account of the restraint of the bearing. It appears that this increased resistance holds down the oil action to the resonant frequency, so that it maintains the vibration even though the rotational speed is raised above that corresponding to the simple oil resonance speed. Also, since the oil is required to do more work, higher oil pressures are developed in the film, and the leakage of oil by the ends of the bearing is increased, as was observed. This explanation of the whipping makes it appear that if it were possible to quiet the shaft when whipping above the oil resonance speed, it would then run smoothly; that the oil action, if it occurred at all thereafter, would have a frequency too high to make the shaft whip. This seems entirely possible. In fact, in a few tests, Model XIIA after being quieted in this way would run smoothly unless disturbed; but a slight shock was sufficient to start it whipping violently again. In general, the oil whip would start itself when the speed and other conditions were right, with no special shock to initiate vibration.

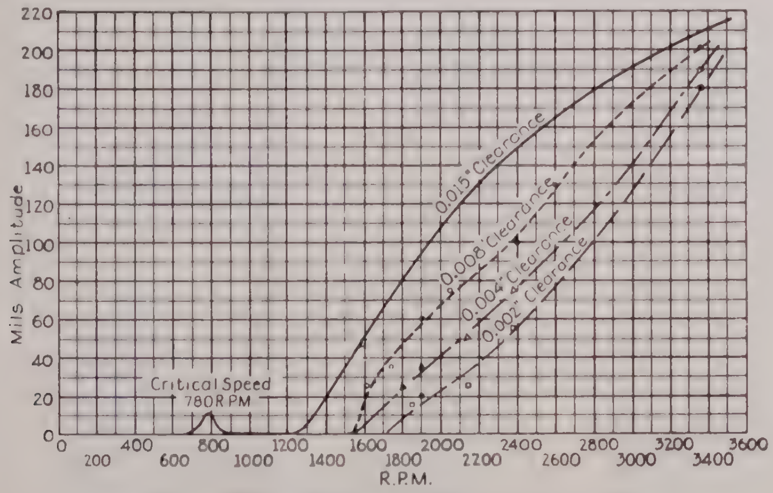

Fig. 9. Effect of Clearance on Whipping of Model XIIB
Shaft horizontal
Bearings 1 in. by 3 in.

Observations and theory agree that the tendency to whip is weakest at speeds just above the oil resonance, and that it increases with increase of speed. It seems reasonable, therefore, that if the damping resistance is large enough, whipping should not develop until the speed is raised considerably above the oil resonance. In the case of Model XIIA set vertically, the end-thrust on the ball bearing may have caused enough damping to prevent the whip building up below 2250 r.p.m. Setting the model horizontally relieved this end-thrust, and the model then whipped at any speed above the oil resonance. The application of a little extra damping in the horizontal position, however, by means of a carbon ring closely fitted at the middle of the shaft and held by spring pressure between two stationary plates, caused behavior corresponding to that observed in the vertical position. Whipping failed to develop except at speeds well above the oil resonance, and the heavier the damping pressure, the higher was the speed required to start whipping.

This explanation of the "oil whip" takes no account of the effect of gravity, which produces an unsymmetrical condition in the bearing when the shaft is horizontal. The minor differences in behavior of Model XIIA in the horizontal and vertical positions may be due partly to the effect of gravity in the horizontal position, though it seems likely that one cause of these differences was the damping effect of the ball bearing which served as thrust bearing in the vertical position, as previously suggested. The generally satisfactory correspondence between the theory and the observed behavior of this model in both positions, however, seems to indicate that the gravity effect was not large enough in this case to warrant special consideration. Later tests, to be described, indicated that in more heavily loaded bearings the effect of gravity may be so large as to suppress the whipping action entirely.

Tests with Various Special Journal Bearings

After the nature of the oil whip was recognized a number of tests were undertaken to investigate whether some modification of the journal bearing would not break up the oil action and prevent whipping. A preliminary change of this sort involved the oil feed arrangement: instead of feeding oil from a lengthwise groove along one side of the bearing, an annular groove was cut in the middle, so that the bearing surface was divided into two unbroken symmetrical parts

This was merely a step toward the next change and was not expected to have much effect on the whipping. Test with Model XIIA set vertically showed that the whipping was more pronounced than before. The same bearing was altered by the cutting of six lengthwise slots in each end of the bearing, which it was thought might serve to prevent the oil action responsible for whipping. This expectation was only partly realized; the whipping was not eliminated but decidedly weakened. It was necessary to run to higher speeds before whipping developed at all, and then its violence was considerably reduced. Trial was next made of a very short bearing with annular oil feed. This change was more effective than the slots, but also failed to eliminate the whipping entirely. Later, with this model set horizontal, two other modifications were tried. A plain bearing with annular feed was relieved in the middle over most of its length, so that there remained only a narrow band of bearing surface at each end. Pronounced whipping developed in operation with this bearing, particularly at high speed, though with rather less violence than with the standard bearing. As compared with the short bearing test, this seemed to indicate some advantage in reducing the length of bearings—even independently of the loading pressure. Another test was made using a bearing, with helical grooves machined in the bearing surface, with right- and left-hand pitch on opposite sides of the annular feed groove at the center. Rotation in one direction pumped oil rapidly out at the ends of the bearing, and permitted some whipping which became rather vigorous at high speed. The model would not whip when running in the opposite direction, but this was not considered of importance because the oil flow was practically stopped due to the pumping action opposing the supply pressure. These qualitative tests indicated several means for weakening whipping, but none of these was satisfactory for completely preventing it in the model.

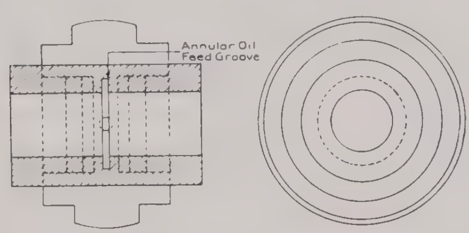

Fig. 10. Proportions of Journal Bearings Used With Model XIIC

Further Tests on the Effect of Bearing Proportions, Etc.

Effect of Bearing Clearance

Model XIIA had been at first equipped with a journal so large as to be out of all proportion to the size of the shaft; this was turned down and reground to a 1-in. diameter, and the bearings bushed accordingly, 3-in. long and with clearances of 2, 4, 8 and 15 mils. The oil was fed through an annular groove. With these changes, the model was designated as Model XIIB. The curves in Fig. 9 show the effect of varying the amount of bearing clearance on the behavior of the model. As the clearance was reduced, the whipping started at higher and higher speeds, but in all cases grew rapidly in violence with further increase of speed.

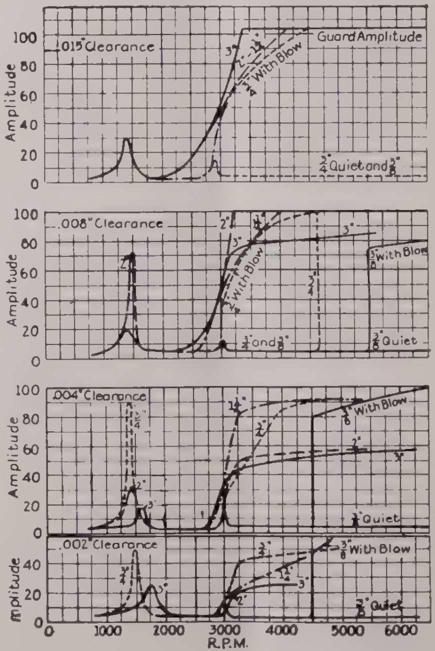

Fig. 11. "Oil Whip" Tests With Model XIIC
Bearing 1 in. dia., length given by figures on curves

Effect of Reducing Bearing Length

It had been intended to test with the same model the effect of using different lengths of bearing by cutting down the original 3-in. lengths to 2 in., 1¼ in., etc. . Only the first series of these tests was completed (with the 3-in. lengths), because the severe vibration encountered at high speeds fatigued the model shaft, and in the first run with a 1-in. by 2-in. bearing, the shaft broke.

It was decided not to duplicate the old $\frac{5}{8}$-in. shaft which had been made of soft steel, but to use a 1-in. chrome-nickel steel shaft which was already available. The same wheel, bearings, etc., were used, the only other changes being the attachment of a new pointer, and a further separation of the bearings. The new combination was designated as Model XIIC, and the set-up is shown in the photograph, Fig. 8. The stiffer shaft caused an increase in the critical speed from 800 to 1400–1770 r.p.m., depending on the clearance.

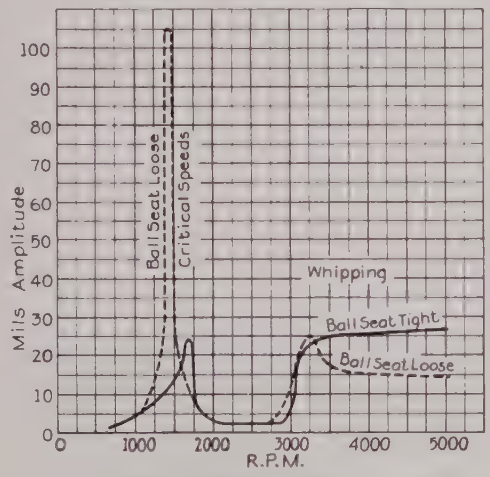

Fig. 12. Effect of Ball Seat Looseness on Vibration Characteristics

An extended series of tests was made with this model, the length of the bearings being cut successively from 3 in. to 2 in., $1\frac{1}{4}$ in., $\frac{3}{4}$ in. and $\frac{3}{8}$ in., as indicated in Fig. 10. The results of these tests are shown in Fig. 11. The most interesting result is the fact that whipping developed in every run but one: the shortest bearing, $\frac{3}{8}$-in. long, with the largest clearance, 0.015 in., failing to support whipping. All the other combinations whipped to some degree. It was noted that the shorter bearings produced less vigorous whipping, though in many cases whipping of greater amplitude. The distinction is that a "vigorous" whip builds up quickly to a definite amplitude when the rotor, running at a whipping speed, is quieted so that it runs smoothly, and is then released. Whipping which builds up vigorously may fail to reach large amplitude because of the restraint of a long bearing having small clearance. A shorter bearing, however, under like circumstances, builds up the whip more slowly but to larger amplitude. The amplitudes reached by the whipping, therefore, are not comparative indications of the intensity of the stimulus. It will be noticed that with bearings of $1\frac{1}{4}$-in. to 3-in. lengths, which included all of the combinations which produced the most vigorous whipping, the whipping started at almost exactly twice critical speed (about 3000 r.p.m.); and further, that the amplitude of whipping never decreased as the speed rose, although the speed was carried in most of the tests to 6500 r.p.m. In every test, also, the shaft was quieted at various speeds, but it almost invariably broke out quickly into violent whipping again when released.

Check on Frequency of Whipping

During the above series of tests, there were some indications that the frequency of the whipping increased with the speed. It was decided to check this point by taking oscillograms. A bearing was rebushed 1 in. by 2 in. with 0.004-in. clearance, and some films taken with the results shown in Table I.

TABLE I

R.P.M.	Whip Frequency	Amplitude
3070	1440	0.040 in.
3200	1523	0.060 in.
3420	1590	0.070 in.
3960	1640	0.085 in.

The lowest frequency, 1440, corresponds very closely to the observed critical speed for this set-up, 1430 r.p.m., at which the amplitude reach 0.030 in. The increase of frequency with the speed is thought to be due to the increase of amplitude, on account of the stiffening of the shaft by the bearing which tends to increase the critical speed. This restraint apparently accounts for the "high criticals" noted with long, tight bearings, which reached as high as 1770 r.p.m. (see Fig. 11). This would also account for the fact that in some cases the whipping was observed to start somewhat below twice critical speed, the critical being observed with larger amplitude and higher frequency than the start of the whipping.

Effect of Looseness of Ball Seats

In general, the whipping with the bearing cap loose was somewhat weaker than that experienced with the cap tight. Loosening of the bearing caps is not a procedure to be recommended, however, for the reason that it permits a much greater degree of vibration (due to unbalance at critical speed) than occurs when the ball seat is tight. An example from test is shown in Fig. 12. This point was also tested out with the heavier model, No. IX. With the same degree of unbalance, the amplitude reached at critical speed was 2 to 3 times as great with the bearing caps loose as with them tight.

Effect of Varying Bearing Loading Independently of Length

In order to determine the effect of increased loading, two additional 200-lb. wheels were made to shrink on the shaft of Model XI. Without these, the model weighed about 400 lb., and the bearing loading was about 43 lb. per sq. in. of projected area; violent whipping had developed at speeds of 3600 r.p.m. and up; the critical speed was then 1970. With the shaft diameter reduced slightly and one extra wheel shrunk on, the critical speed was reduced to 1700 r.p.m., the average loading was increased to 64 lb. per sq. in., and the model whipped just as violently as before from about 3100 r.p.m. upward. Two differences, however, were noted: the whipping seemed to depend principally upon the more lightly loaded of the two bearings; and at speeds above 4000 r.p.m., the whip diminished somewhat in amplitude unless a large increase in oil supply was given to the bearings. The loading was increased to 85 lb. per sq. in. by the addition of the other wheel, and the critical speed thereby reduced to 1425 r.p.m., the model now would not whip at all at any speed up to 4000 r.p.m. The indication is that the oil whip may be avoided by the use of sufficiently heavy bearing loading pressures.

Summary and Conclusions

A new cause of shaft whipping has been found which seems to account for the resonant whirling of shafts running in well lubricated journal bearings at speeds of about two times critical speed or higher. The source of the stimulus supporting the whipping has been found in the oil film in the bearings. A theory is proposed to account for the action of the oil in producing the resonant vibration of the shaft. This theory was checked and extended by test results on models. It appears that the oil film tends to produce a forward movement of the journal around in its clearance, at a frequency equal to about half running speed, or less if much frictional resistance to the whirling motion must be overcome; and that this oil stimulus comes into resonance with the shaft when the speed reaches about twice critical speed, producing resonant whirling, or whipping, of the shaft. This continues with increasing violence at all higher speeds, with sufficient oil supply, the frictional resistance to whirling serving to hold down the oil stimulus to the resonant frequency. In tests with models it was found that this form of whipping could be stopped or prevented in a number of ways:

(1) By shutting off the oil supply to the bearings
(2) By misalignment of bearings
(3) By steadying the shaft
(4) By confining operation to a speed range below twice critical speed
(5) By the use of a friction-damped bearing
(6) By avoiding very light bearing loading pressures

Of these remedies (1) and (2) are obviously impracticable for commercial application, and (3) involves making contact with the shaft, which also is undesirable. The other three are practical means to avoid the trouble.

Early Textile Electrifications in the South

By B. S. Havens

Publicity Department, General Electric Company

In the enormous rush of modern industry it is interesting once in a while to step aside from the present and go back to the days when the Electrical Age was just opening. Men in all walks of life take a quiet pride in reviewing the pioneer accomplishments with which their predecessors began to build the modern structure of industrial civilization. Thus it gives us a feeling of satisfaction in presenting this article by Mr. Havens to think that these, the earliest electric installations in cotton mills, should have proved so successful that they are still in use, and so far in advance of the general practice of that day as to have initiated a new era which has since spread to the huge proportions with which we are familiar in 1925.—Editor.

The first application of induction motors in a textile mill either in this country or abroad was at the plant of the Columbia Mills, Columbia, S. C. This was the first mill in the world to install a complete electric generating plant for the purpose of operating motors located on the premises, and also the first to adopt the plan of subdividing the mill into independently driven sections. With the exception of two standard, single-phase generators of small capacity, operated as synchronous motors, and one direct-current motor, there were no other motors in operation at that time in any textile mill. In these two exceptions, the machines were used only as supplemental power because the main power plant of the mill was located too far distant to permit the mechanical transmission of power to the place where it was needed.

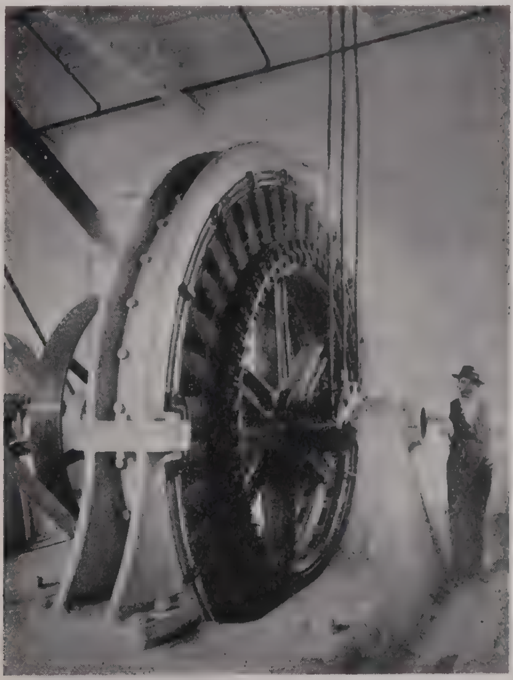

Fig. 1. One of the Original 500-kw. Generators Installed at Columbia Mills

Investigation of the Columbia installation today discloses the fact that the electrical machinery originally installed is still running and giving satisfactory service. In view of the fact that the manufacture of electrical machinery was in its early development stages at the time the Columbia installation was made, it may be interesting to review the circumstances surrounding this original electrification.

The problem which faced the Columbia mills in 1893 was the adaptation of mechanical drive—then the accepted method of mill operation—to peculiar local circumstances. A canal which it had been planned to use for water power was located between the river and the site selected for the mill, and it would have been necessary to build an expensive flume from the canal to the basement of the mill where the wheels would have been situated, and also an expensive tail race to carry the water from the wheels underneath the canal to the river. In attempting to solve the problem, the mill officials even gave consideration to the location of a power house on a narrow strip of land between the river and the canal and transmitting the power by ropes, a distance of approximately 800 feet, to the mill.

Finally, however, it was decided to install the three-phase electrical system. This decision was made after reviewing propositions from three competitive manufacturers, two of whom suggested the use of direct-current motors of large size to drive the shafting which would ordinarily be used in a mechanically driven mill. The General Electric Company, however, adhered to its recommendation that induction motors would give the best results and in April, 1894, this company installed two 500-kw., 108-r.p.m., three-phase generators direct-connected to two pairs of 48-inch horizontal waterwheels. Fourteen 65-h.p.

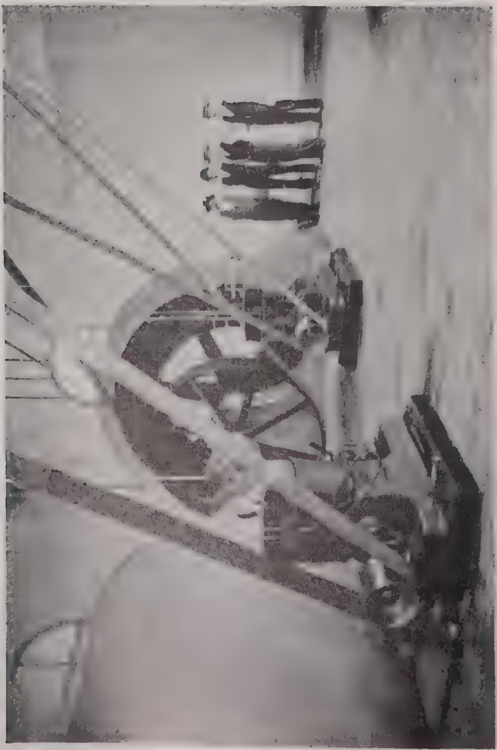

Fig. 2. Section of the Old Generating Room at Columbia Mills

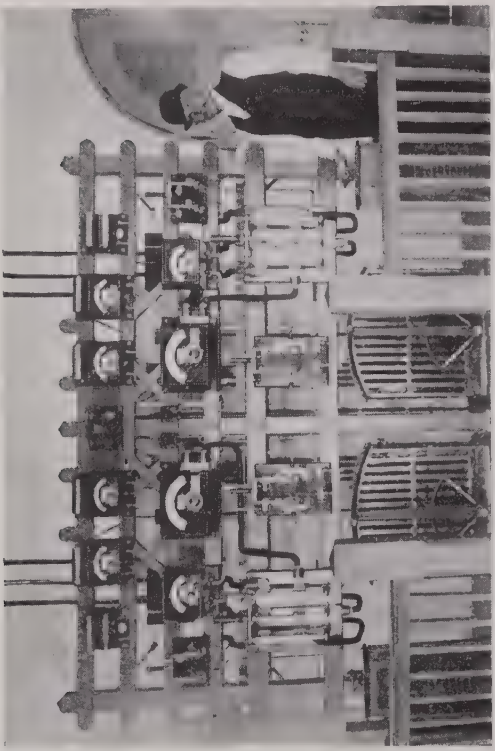

Fig. 3. An Early Switchboard at Columbia Mills

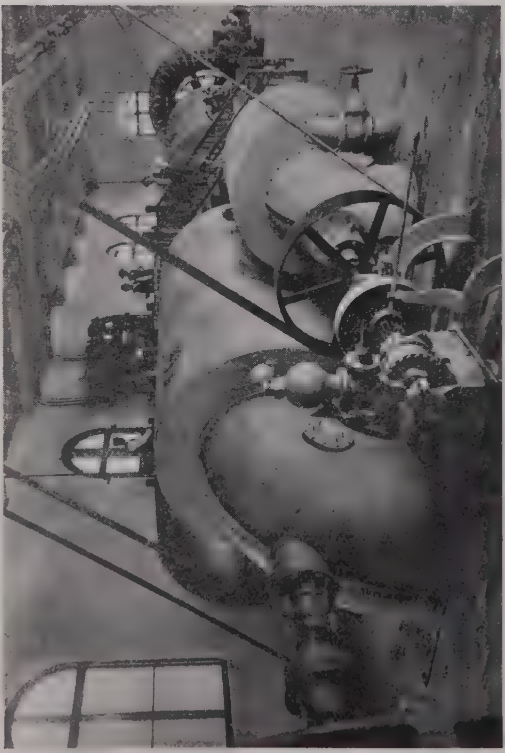

Fig. 4. General View of the Columbia Mills Generating Room 32 Years Ago

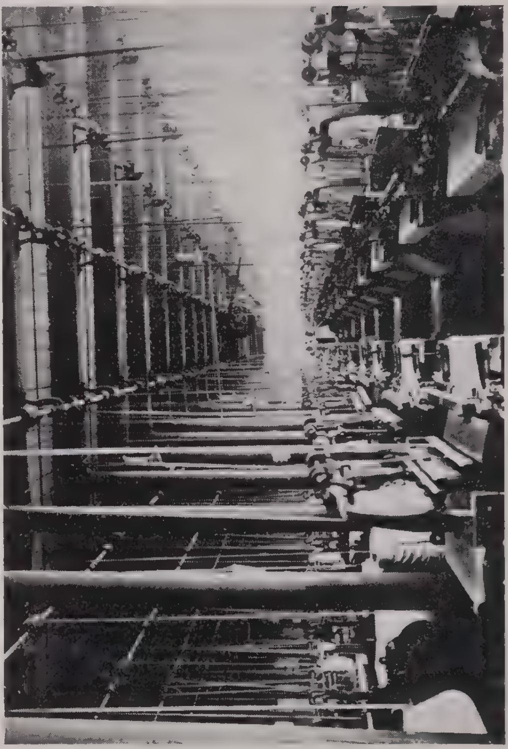

Fig 5. The Old Weaving Room, Mill No. 4, Pelzer Manufacturing Co.

induction motors were installed for operating the mill. The generators and the motors are still in service.

Two 15-kw. exciters were installed with the generators, and the equipment included, besides a switchboard and miscellaneous station equipment, an auxiliary lighting circuit for 700 sixteen-candlepower lamps. The contract stipulated that the installation was to be completed in 14 days after the assembly of the apparatus on the premises of the Columbia Mills; and there was to be guaranteed a maximum efficiency of 80 per cent between the shafts of the generators and the pulleys of the motors. The transmission line was but 700 ft. in length and the switchboard was of the skeleton frame type, of hard wood, located in the generating room. On it were mounted "four ampere meters, two potential indicators, two regulators, lightning arresters", etc.

The cables running from the power plant to the mill were laid in a wooden trough. This was filled with insulating compound and then buried in the ground. No trouble has been experienced with this original cable and it is still in service.

The installation is remarkable in many ways. At the time the Columbia Company was considering the electrification, the purchasing agent, Mr. Oliver, asked where he could inspect a similar installation, and was told that there was no other in existence.

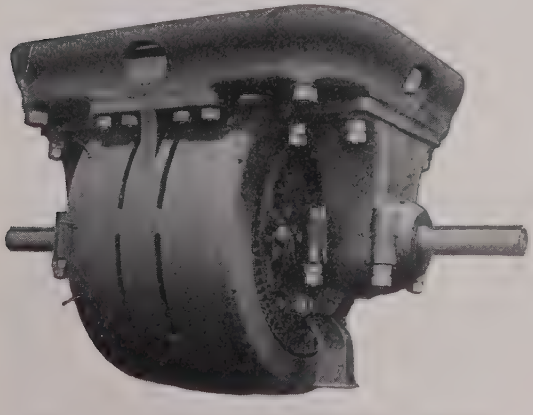

Fig. 6. One of the Columbia Mills Motors, Inverted for Ceiling Mounting

It was to be the first installation where motors were inverted and placed on the ceiling. As it was then General Electric practice to use pillow blocks on its motors, the oiling problem was quite serious. It was the first instance, also, where the shaft was extended at both ends. In the main mill the shafts of the motors thus designed drove belts running in opposite directions. This scheme was adopted on the theory that the load on the bearings would be very much reduced.

As a matter of fact, five of the motors are still running on their original sleeve bearings. Rewinding has been actually necessary on but five of the stators, although seven have been rewound. On two of those the rewinding was done as a precautionary measure, the two motors having become spares when replaced by larger units where loads were increased. One of the two was put back into service soon after rewinding in place of a 100-h.p. motor on which the load had been decreased.

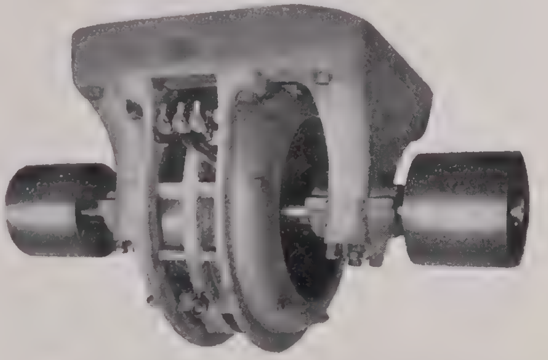

Fig. 7. One of the Old Motors, Showing Pulley at Both Ends of the Shaft

On two of the rotors binding wire was broken and had to be renewed. Aside from this and ordinary resistance clutch repairs, these rotors have given practically no trouble in 32 years.

The regular load which the motors carry ranges from 80 to 85 h.p., although their normal rating is 65 h.p. Some of these motors, in addition to 32 years of day operation, have run for at least 10 years on night service, giving an equivalent of 42 years' operation. When it is considered that, in the night-and-day service, the motors were heated from day operation and did not have sufficient time to cool off before starting up again for the night, the record becomes the more remarkable.

Induction motors of this horse power rating were very large machines in 1894. The General Electric Company had just developed a line of tri-phase induction motors and the largest size that had been built before the electrification of the Columbia Mills was a 10-kw. (13.4-h.p.) machine, and the largest size that had been sold was a 5-kw. (6.7-h.p.)

machine.⁽¹⁾ In those days alternating-current motors were rated in kilowatts, not in horse power, and the Columbia motors were sold as 50-kw. machines.

It may safely be said that the Columbia electrification was directly responsible for the tremendous electrification which has followed in textile mills through the country. To this installation also may be traced, to a large degree, the growth of the textile industry in the South.

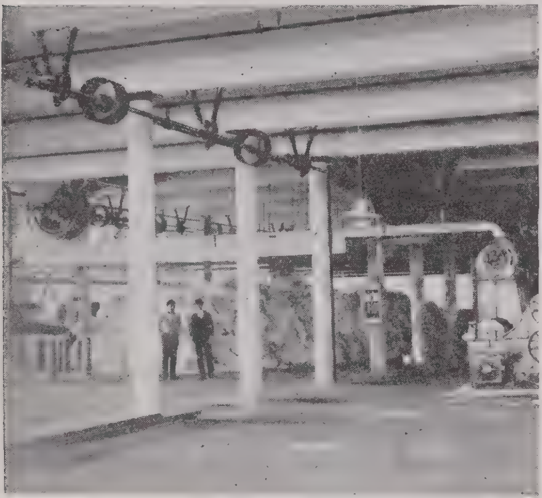

Fig. 8. Old Picker Room, Mill No. 4, Pelzer Manufacturing Co.

Although the Columbia transmission system was not very long, it showed what the possibilities were, and the following year the Pelzer Manufacturing Company, at Pelzer, S. C., installed a plant where the transmission of power was carried about 2¾ miles. In a General Electric bulletin dated February 1, 1895, is found the following comment on this electrification:

"A contract accepted by the Pelzer Manufacturing Company of Pelzer, S. C., involves the installation of one of the most interesting three-phase power plants in the world. The generating station is three miles from the cotton mills owned by that company. At the power house three slow-speed generators, 750 kilowatts each, direct-coupled to waterwheels running at a speed of 167 revolutions per minute, will feed current at 3300 volts (full load) into the transmission lines without transformers.

"The circuit will consist of 18 No. 00 wires, this size having been selected rather than a larger wire, to reduce line induction to as low a figure as possible under the existing conditions. At one mill will be located a 400-h.p. synchronous motor receiving current direct from the lines. At another mill there will be installed more than 20 induction motors throughout the various rooms. Fourteen of these will be 110-h.p. motors and the others, of various sizes, from 5 to 75 h.p. In the substation will be located nine 175-kw. transformers for the motors and for 1200 incandescent lights for the mill. Two motor blowers of three horse power each will be used for cooling the transformers."

Captain Ellison A. Smythe was responsible for placing the order, and the stock for capitalizing the enterprise was largely subscribed to by Captain Smythe's friends in Charleston. When it became known in that city that Captain Smythe had entered into the contract—an absolutely new experiment—the price of Pelzer stock fell $25 a share in the Charleston market.

The skeptical reaction of the public at the time of the Pelzer electrification was but an indication of the common attitude towards electricity and the general ignorance of its principles existing at that time. One of Captain Smythe's acquaintances, whom he met on the afternoon of the day the plant was put into operation, offered his condolences to the Captain in the "failure of the electrical transmission system," saying that he had watched the wires all day long and they had

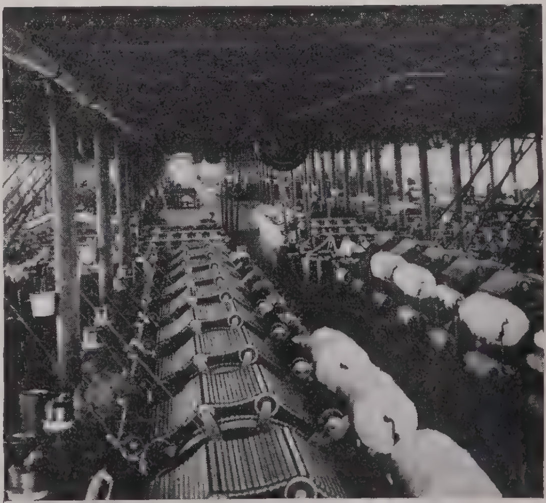

Fig. 9. The Card Room, Mill No. 4, of the Pelzer Plant

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(1) This motor, incidentally the first multiphase induction motor to be placed in commercial operation on a central station line in this country, was recently obtained by the General Electric Company for exhibition purposes from the Page Belting Company's plant at Concord, N. H., where it was driving a group of machines through line shafting.

not moved. He had seen a mill operated by rope drive and it was his belief that the wires must travel, as if moving over pulleys, between the power house and the mill. The transmission line passed over the mill village and some of the operatives placed pails beneath the wires "to catch the electricity that fell off."

The success of these early installations of electric drive in cotton mills was so pronounced that the number of spindles in the south has increased from 4,000,000 in 1898 to 17,000,000 in 1923, representing an investment of one billion dollars. At this rate of increase, the south in ten years will have as many operating spindles as the entire United States has today. It is estimated that the southern textile mills consumed one billion kilowatt-hours of electricity in 1923.

For the historical information contained in this article the writer wishes to make acknowledgment to Mr. Sidney B. Paine, Manager, Textile Division, General Electric Industrial Department, who, with Mr. A. R. Bush, Manager of the General Electric Industrial Department, handled the sale and installation of both the Columbia and Pelzer electrifications.

The Technique of Examining Metals Under the Microscope

PART I

POLISHING THE SPECIMEN

By Gustav Pirk
Research Laboratory, General Electric Company

While the unaided eye functions best for the all-round purpose of sight, the wide spread of its normal working angle places a limit on the smallness of the objects which it can distinctly see. By artificially decreasing this optical angle with the microscope, there becomes available a new range of vision within which much is revealed of the structure of materials. The inspection of metals by this means is particularly fruitful, both for research investigation and factory routine testing. Much of the success of this type of analysis lies in the proper preparation of the specimen, but unfortunately an adequate knowledge of the means has not been readily available. For this reason we are here presenting a discussion of the first step of the process, grinding and polishing, to be later followed by a description of the etching operation, and finally a treatment of the actual inspection under the microscope.—**Editor.**

The method employed in the preparation of metallic microsections is entirely different from that used for the ordinary preparation of biological or petrological sections. Staining or similar methods to make the various parts distinctly visible under the microscope cannot be employed with metals because their thinnest sections are opaque. Neither is it possible to secure a section as readily as is usually the case with biological or organic sections. Often, because of the nature and character of the mechanical and thermal treatment that a metallic specimen has received, it is relatively difficult to secure a satisfactory microsection.

The physical properties of the metal must first be very carefully considered. That is, such properties as hardness, malleability, and ductility determine the degree of care that must be exercised in preparing the section and the method which must be employed. With the softer metals and alloys it is necessary to exercise special precautions in order that the crystal structure and other details, which are to be visible under the microscope, may not be destroyed nor distorted. This care is particularly necessary with the light metal alloys. Of all the soft metal alloys which require delicate methods of preparation, those of aluminum probably present the greatest difficulties. The slightest departure from standard technique will often cause all one's efforts to have been spent in vain.

Before cutting a section of metal from an ingot or casting for microscopical examination, it is well to give thought to the purpose of the examination, and the condition under which the ingot or casting has been produced. This forethought will often enable the examiner to tell with certainty the nature and origin of the constituent which is visible. The value of the previous history of a metal cannot be overestimated. In the case of steel, and such metals that have received heat treatment, it is absolutely necessary that the composition and heat treatment be known.

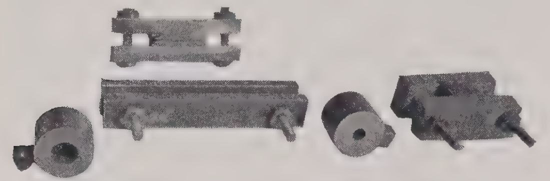


Fig. 1. Various Types of Clamps for Use While Grinding Specimens for Examination Under the Microscope

The section which is to be examined should also be selected with the following points in view: first, the conditions under which the casting was produced; and, second, the size and shape of the casting. All castings are likely to vary in shape and area of cross-section, and this variation necessarily produces varying rates of cooling which very markedly affects the structure of the metal. For this reason it is advisable to take several sections from various parts of the casting. These specimens should be cut from the casting or ingot in various planes or directions.

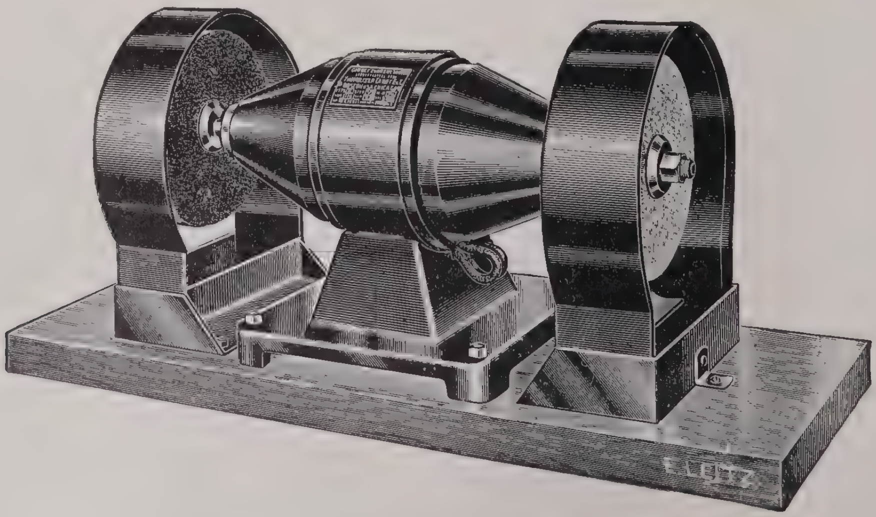


Fig. 2. Combined Grinding and Polishing Machine

The specimen should also be selected with regard to the homogeneity of the metal. Where structural changes are likely to have been produced by mechanical working or heat treatment, it is again advantageous to cut several sections. If these are taken so as to represent the structure from the surface to the center, then little difficulty will be experienced in ascertaining the effect of cooling, shape, size of the cross-section, etc. Castings produced in iron or metal molds have layers of chilled surface metal, the structure of which can be seen only when a number of sections are taken from the outside to the center of the mass. Usually it is desirable to remove the surface skin of metals or alloys which have been heat treated. The heating and quenching operations produce a surface layer which, when examined under the microscope, is not a truly representative section of the specimen and will lead to incorrect conceptions of the treatment. Thus, when steel is heated in a furnace prior to quenching, part of the metal near the surface becomes decarbonized; and when such a section is viewed under the microscope it may lead to the drawing of false conclusions.

Cutting the Specimen

After definitely deciding just what portion of the casting or ingot is to be examined, the next step is to cut the specimen. This sample should be of such size that it may be handled conveniently during the polishing process and under the microscope, a convenient size being about ½ in. square by ⅝ in. thick.

If the section to be examined is a wire, it is usually held in a clamp embedded in lead or Wood's metal. If a cross-section is to be made of a number of sheets of metal, sheet steel for instance, some five or six are taken and lightly held in a clamp. The pressure exerted by the clamp should be just sufficient to hold them firmly together without causing them to be strained. Hard metals like tungsten may be pressed into copper without causing any deformation of the specimen. This can be done by taking a copper block with parallel faces, placing the tungsten on it, and then on top a piece of hard steel which has a plane surface, and the whole compressed. On removing the steel plate, the tungsten will be found firmly imbedded in the copper. Fig. 1 illustrates some of the various devices used for holding specimens during grinding.

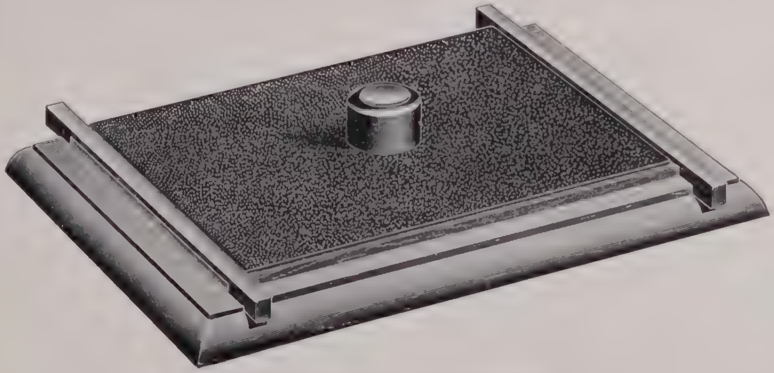


Fig. 3. Simple Hand Grinding Board

For the cutting of such metals as zinc, brass, copper, iron, untreated steel, etc., the hack saw will ordinarily produce the desired result. In the case of some brittle metals, however, it is necessary to resort to other methods for obtaining the specimen. Occasionally it is possible to break a piece of metal from the casting with a hammer, but this operation is open to the justifiable criticism that the structure may be distorted or otherwise injured. To obviate these serious objections another method may be employed, that of cutting off the specimen by an emery or carborundum disk. During this operation care must be taken not to heat the specimen, as some structural transformation is likely to occur. A generous supply of water, or some other cooling agent, should be constantly kept flowing on the specimen. This method is also used for metals like tungsten and molybdenum, only in this case no heat transformation is likely to occur.

The oxy-hydrogen or oxy-acetylene torch should never be used if one expects to obtain a representative microsection of the metal under examination. The intense heat of the flame completely obliterates any structural peculiarities of the metal, and so makes the result of the examination worthless.

Grinding the Specimen

The next step in the preparation of the microsection is that of grinding. This may be done entirely by hand or machinery, or by a combination of the two methods. As a preliminary to hand grinding, it was the practice to hold the specimen in a vice and flatten its test surface by filing. This method, however, proved unsatisfactory for two reasons. First, the grip of the vice sometimes strained the specimen and injured its structure. Second, the scratches produced by the file are so coarse that the metal is strained to a considerable depth. It is exceedingly difficult to polish out these scratches and get down to the structure of the undeformed metal. The filing stage of the process has therefore been replaced by grinding, either by hand on emery paper or by revolving disks to which the paper is glued.

For machine grinding, use is made of an emery wheel about 8 or 10 in. in diameter, running at 600 to 800 r.p.m. Such a wheel is shown in Fig. 2. The cuts produced by emery are more numerous and much smaller than those made by the file, thus leaving a surface which is not disturbed to such a depth.

When using the grinding wheel care must be exercised not to overheat the metal, particularly heat-treated steel, as some very serious heat transformations may occur due to the rise in temperature. This difficulty may be avoided by dipping the specimen in cold water frequently. The intermittent removal of the specimen from the wheel gives rise to a new difficulty, however, if the wheel is a fast running one, for a new facet is ground on the specimen each time it is placed in contact with the wheel. The remedy is to use a low-speed wheel, so that one can feel for the original facet before permanent damage is done.

Fine Grinding

The specimen is now ready for the next step, that of fine grinding either by hand or on a disk to which the various grades of emery paper are glued. If the hand method is used, it is desirable to start with No. 2 paper, rubbing the specimen in a straight line to and from the operator. This process is carried on until all the scratches left by the previous paper are effaced. Light and uniform pressure should be employed, otherwise the specimen will rock and the edges become rounded off. This grinding process is carried on until all the papers from No. 2 down to No. 000 have been used. When passing from one grade of paper to the next finer, the specimen is to be rotated through an angle of 90 deg. and rubbed on that paper until all the scratches produced by the previous paper have been eradicated.

These papers should be kept in a place where they cannot accumulate dirt and grit, as such foreign substances are likely to produce deep gouges in the specimen during the fine grinding.

If machine grinding is employed, the various papers are glued to separate disks and the same instructions are followed. The disks should run at about 600 r.p.m. Other devices, such as an endless belt running over a flat surface, sometimes are used and also give satisfactory results. In all cases the emery paper must be backed by a plane hard surface, such as a hard rubber plate or a pane of glass.

For all delicate work hand grinding should be employed, but for the harder metals and alloys much time can be saved by machine grinding. Fig. 3 illustrates a hand grinding board, and Fig. 4 the endless belt type of grinding machine. If the latter be used for coarse grinding, best results will be obtained if the grinding is completed by hand.

Polishing

The forced polish given by rouge on chamois is very attractive to the eye, but is useless for metallographic examination, because the entire surface of the metal is smeared. To produce the type of polish which is essential for metallographic work, it is necessary to use a piece of soft cloth or leather and a fine abrasive powder of a definite grade held in suspension in some liquid, usually water. Alloys and metals that are attacked by water can be polished by using a liquid such as petroleum or benzol.

The powders commonly used are the oxides of iron, aluminum, chromium, and magnesium. They are prepared by levigating the powdered oxide and are designated as 3, 6, 12, or 24-hour powders, according to the time which they require to settle out.

For various metals and alloys different grades and kinds of powder must be employed. Recommended combinations are given in

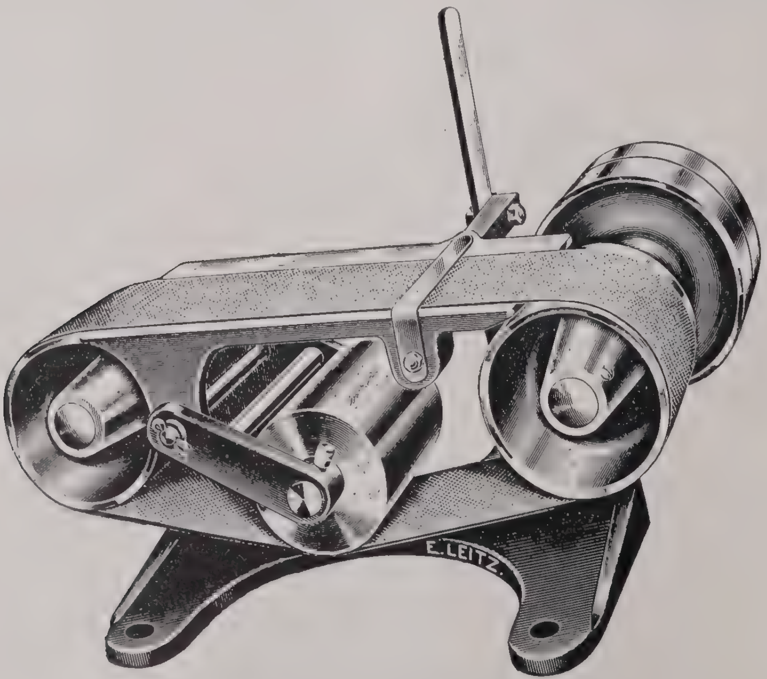


Fig. 4. Endless Belt Type of Rough Grinding Machine

Table I. The abrasive liquid should not contain more than 3 to 10 grams of the powder per liter.

It is necessary that the powder be distributed on a support, for which purpose broadcloth or a good grade of felt is employed. The cloth must be smooth and of a fine texture, otherwise it will scratch the metal even after it has been thoroughly washed,

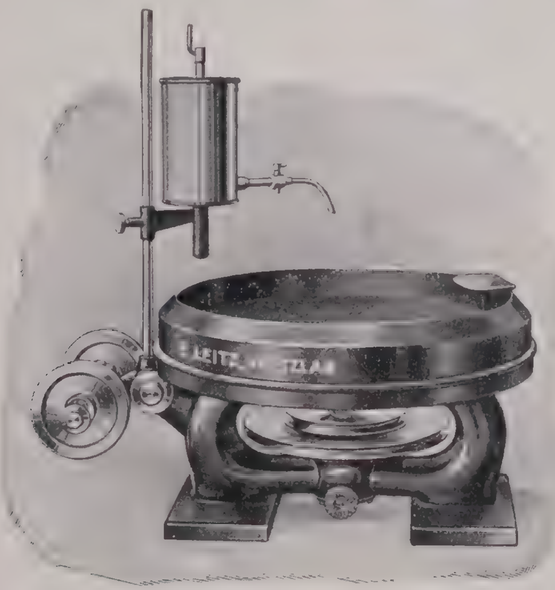


Fig. 5. Polishing Disk with Reservoir for Solution of Polishing Powder

The operation of polishing is usually performed mechanically, the specimen being held lightly against a rotating disk made of some hard material over which the polishing cloth is tightly stretched. The disk is usually 8 to 10 in. in diameter and runs at a speed of about 250 to 300 r.p.m. The polishing powder is sprayed or poured onto the rotating disk which should be kept moist in this manner at all times. During polishing, the specimen is moved in a circle and in a direction opposite to that in which the disk is rotating, for this will work any coarse particles out from under the specimen. Fig. 5 illustrates a type of polishing disk for this purpose.

While the edges will become slightly rounded, this is of little consequence except when it is necessary to examine the surface of the specimen to its edges, as in the case of fractures, or to preserve slip bands, for which purpose the specimen may be embedded in Wood's or white metal. The same result may also be accomplished by copper plating with a cyanide bath. This operation will generally require several days because of the necessarily low current density used.

If all the previous steps of fine grinding have been well executed, a specimen of the size mentioned should be freed from the No. 000 scratches in four or five minutes. Fig. 6 illustrates the effect of the various grinding and polishing operations.

Continued polishing diminishes the luster due to the surface becoming pitted. After the sample is completely freed from scratches it should present a smooth, featureless, mirror-like surface, unless one of the following conditions is present:

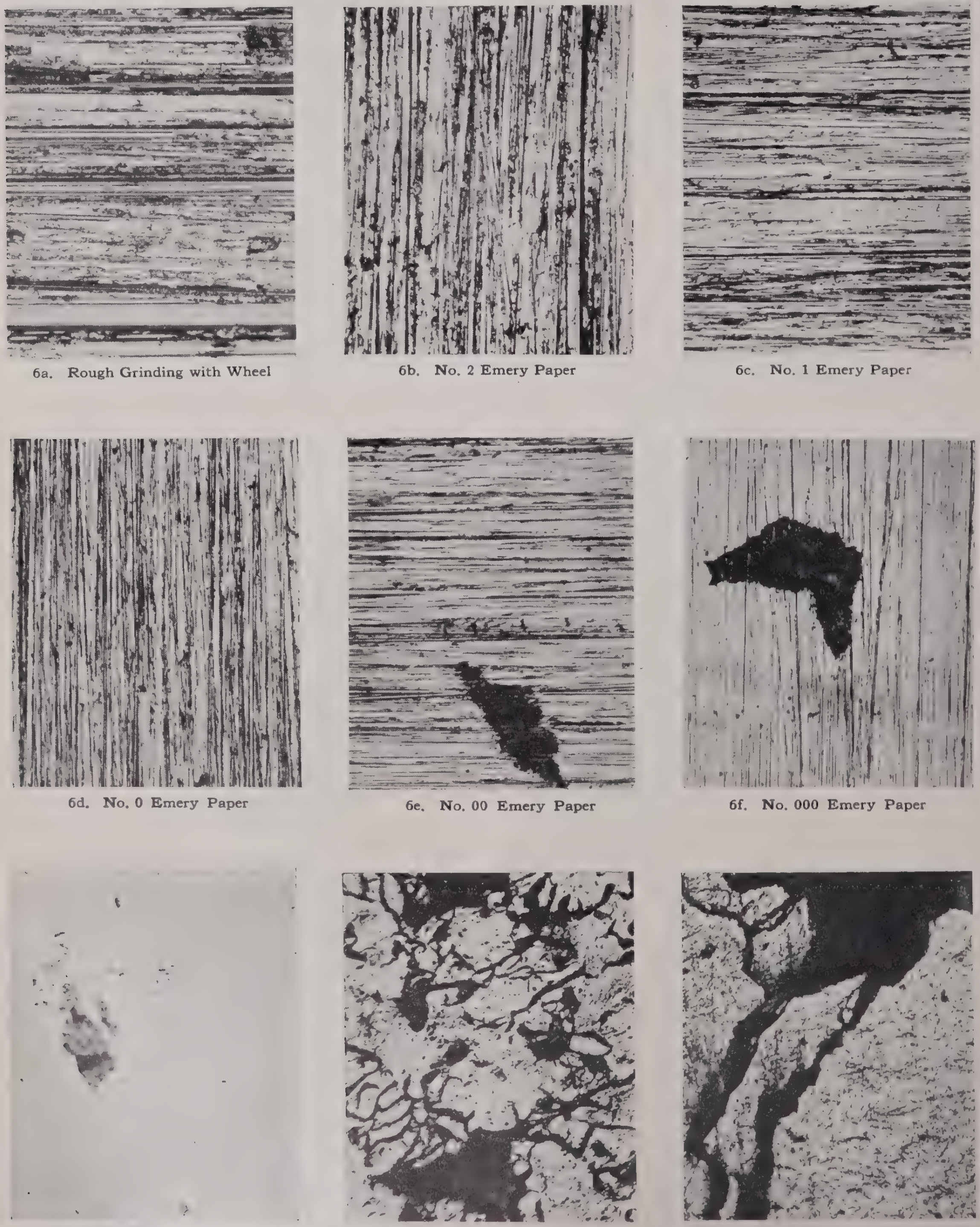
(I) The constituents are of a different color, as shown in Figs. 6g and 6h. This is the case with the copper-antimony alloys where the Cu_2Sb_9 violet network outlines the antimony grains very distinctly. The same is true of most of the aluminum alloys.

(II) The constituents vary in hardness. Where this condition exists selective polishing will take place and one of the constituents will wear faster than the other, leaving one standing in relief, as in Fig. 6g. This is the case with the white bearing metals which contain Cu and Sb. With these alloys the Cu Sb constituent will always stand in relief.

(III) The metal is porous, as in Fig. 6h. Under this condition black spots or cavities will be noticed over the entire surface. These act as grit and dirt collectors and should be washed out after grinding on each grade of emery paper. If a casting having many cracks is to be examined, Fig. 6i, these should be filled with some plastic material, such as shellac or paraffin.

TABLE I

Metal	Powder Recommended
Iron, Steel, or Cast Iron	Alumina Rouge *(12-hr. powder)*
Aluminum, Copper, or all soft metals	Magnesium Oxide *(24-hr. powder)*
Nickel, Cobalt, Tungsten, or Molybdenum	Alumina *(12-hr. powder)*
Lead or Tin and their alloys	Chromium Oxide Magnesium Oxide *(24-hr. powder)*



6a. Rough Grinding with Wheel

6b. No. 2 Emery Paper

6c. No. 1 Emery Paper

6d. No. 0 Emery Paper

6e. No. 00 Emery Paper

6f. No. 000 Emery Paper

6g. Wrought Iron
Final polish with rouge

6h. Cast Iron
Final polish with rouge

6i. Steel
Final polish with rouge

Fig. 6. Photomicrographs Taken at 150 Diameters of Successive Steps in Polishing a Wrought-iron Specimen Figs. 6a-6g), and Polished Specimens of Cast Iron and Steel (Figs. 6h and 6i)

The Mechanics of Grinding and Polishing

It was long thought that during the process of fine grinding and polishing, the pits and scratches became smaller and smaller, and finally sub-microscopic in size. This is, however, not the case, for the metal actually undergoes a small amount of plastic deformation.

The action of metal-cutting tools is now fairly well understood. A pressure great enough to produce rupture is exerted on the section being cut; and although rupture takes place only along a small line, there will obviously be a portion of strained metal around the groove, produced by the cutting tool. This area of strained metal becomes greater the larger the cut taken, because the pressure is brought to bear on a correspondingly larger area. This is what also occurs when the coarse grades of emery are employed, only the cuts are much more numerous and very much finer. Thus the depth to which the metal is deformed or strained is considerably less.

If we turn to the metallographic polishing process by means of the polishing wheel and powder, a phenomenon is encountered which is quite different from that of grinding. When the metal is placed on the polishing wheel, the mechanical strain produced is sufficient to convert it into a hard, brittle amorphous mass. While the metal passes from the crystalline state to the amorphous condition, it assumes a temporary state of plasticity. While in this condition it can flow a small amount, which permits the grooves left by the emery to flow together gradually and the surface to smooth itself out. This phenomenon is similar to the action of surface tension in the smoothing out of brush marks on a freshly painted surface.

Beilby has shown that the grooves left by emery also have a tendency to flow together and smooth out, only that the grooves left by the coarse grades are too wide and cannot flow together. As the grooves become finer and finer, the flow of the metal becomes quite visible under the higher magnifications. When a surface is subjected to the action of a suitable polishing powder and wheel the action becomes intensified. Under these conditions the abrasive action becomes negligible. The polishing process helps the metal to assume the plastic state, i.e., temporary mobility, so that by surface tension the grooves may run together and make the surface of the metal smooth. This characteristic is produced by the intimate contact between the molecules of the polishing powder and the surface molecules of the metal. Polishing by this method is to be distinguished from that known as "buffing," because in the latter the polish depends entirely upon mechanical strain, so that the metal is smeared. On etching such a surface the old grooves and irregularities appear and make it worthless for a metallographic examination.

There is, however, another factor which, according to Rosenhain, enters into the mechanism of polishing, i.e., there is a peculiar kind of chemical reaction between the polishing powder and the metal. This results in a forced solution of the polishing material in the metal for a slight depth. There are several facts which support this hypothesis. One is that the color of the surface of a polished specimen varies with the kind of polishing material used. Silver shows this effect beautifully, it being darker when rouge is used than when (white) alumina is employed. Another fact which goes to support this view is that the chemical activity of a surface varies with the character of the polishing material. Here again silver shows this effect. It very frequently happens that silver which presents a very bright surface when polished with rouge will expel small particles of it from the surface.

Not all soft substances can be employed as polishing materials. It was first thought that consideration need be given only to the shape of the material particles. All successful polishing materials, however, have later been found to belong to one class of chemical compounds, that of oxides. Certain metals are known to dissolve their own oxides. This property may therefore bear directly on the mechanism of polishing, as a metal which has a small percentage of oxide dissolved in its surface layer will undoubtedly be more mobile and plastic than a metal without this "forced solution," just as the addition of an alloying element to a metal increases its mobility.

It is thus seen that the smooth surface of a polished specimen is the result of several phenomena which when combined tend to give the metal a degree of mobility sufficient to smooth it out under the action of surface tension.

The specimen after being polished is then ready for etching.

(*To be continued*)

A Short Method of Calculating Flywheels

WITH REFERENCE TO RECIPROCATING AMMONIA COMPRESSORS DIRECT-CONNECTED TO SYNCHRONOUS MOTORS

PART I

HISTORICAL DEVELOPMENT

By A. R. Stevenson, Jr.

Engineering General Department, General Electric Company

In arranging for the drive of a refrigerating compressor, one of the major problems has been the determination of the minimum flywheel effect that will transform the periodically varying torque demand to a comparatively uniform load. A satisfactory solution to this problem is of special interest to power companies because a refrigerating load has the desirable feature of 24-hour-a-day constancy, but with improper flywheel action may vary from maximum load to some negative value of torque several times a second. To this end the Electric Power Club has co-operated with the members of the American Society of Refrigerating Engineers in formulating a set of regulations to which the performance of motor-driven compressors should conform. A further contribution to the subject is the article below, which we are reprinting in two parts from *Refrigerating Engineering*, and which gives a complete discussion of the whole situation, together with an improved method for the accurate calculation of flywheels for this service.—Editor.

Some years ago, when several companies were asked to make recommendations for a flywheel on any particular installation, the various flywheels proposed covered a wide range of sizes, depending on the company submitting the design. The reason for this was partly due to the fact that no common standard of performance had been agreed upon to which the various designers could conform.

Recently the American Society of Refrigerating Engineers and the Electric Power Club have recommended a standard which limits the amplitude of current variation to 66 per cent of normal.

It should be especially emphasized that this variation is the actual change in current which would be shown by an oscillograph, as described in Paragraph 6(a) of the specifications.(1) Fig. 1 shows an oscillogram of a current variation, and the dotted lines represent the envelope. The ordinary ammeter will not read this variation correctly.

Reasons for Limiting Current Variations

In order to understand this requirement, the harmful effects of too great a current variation will be discussed, and the reasons given for establishing a limit of 66 per cent. The question can best be considered from three standpoints: (1) the user's, (2) the motor builder's, and (3) the power company's.

(1) The user is probably interested in whether or not a large current variation will increase his power bill and repair bill. An alternating-current ammeter reads the square-root of the mean square of the current, and, if the current is fluctuating, the ammeter will read more than the average current. Fig. 2(2) shows the per cent increase of effective current for different amounts of current variation. Thus, with 130 per cent current variation the ammeter will read 10 per cent high. Luckily for the customer, the watthour meter will not register this additional 10 per cent.

Fig. 2 also shows a curve marked "Heating." If the current is fluctuating 130 per cent, the value of I^2 will be increased 21 per cent. This means that the resistance losses in the motor and in the leads will be increased by the same amount. The armature I^2R loss in an ordinary synchronous motor is about 2 per cent. With 130 per cent current variation this would be increased to about 2.4 per cent. Thus the motor efficiency is reduced about 0.4 per cent by a current variation of 130 per cent. The watthour meter will read this extra loss and will also read a 21 per cent additional I^2R loss in the leads between the motor and the meter.

A large current variation causes violent fluctuations in torque. If the current variation is 130 per cent, the torque will swing from 35 per cent to 165 per cent during each revolution. This has a tendency to shake the coils in the stator, chafing the insulation and finally causing a break-down, unless the motor builder has taken special precautions in supporting the coils. A deterioration of this sort is slow and would probably not take place in the first year or two. The result is that such a break-down occurs after the motor builder's guarantee has elapsed.

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(1) Paragraph 6(a) of the specification reads as follows: (a) The basis of determining this variation shall be by oscillograph measurement and not by ammeter readings. A line shall be drawn on the oscillogram through the consecutive peaks of the current wave. This line is the envelope of the current wave. The variation is the difference between the maximum and minimum ordinates of this envelope. This variation shall not exceed 66 per cent of the maximum value of the rated full-load current of the motor. (The maximum value of the motor armature current to be assumed as 1.41 times the rated full-load current.)

(2) Calculated by H. V. Putman, July 26, 1922.

(2) The motor builder is, of course, interested in limiting the current variation, in order to assure successful operation of the motor.

The total motor losses which determine the heating are, perhaps, 6 per cent. This includes a 2 per cent armature I^2R loss. If the armature I^2R is increased by 21 per cent, the total losses will be 6.4 per cent, and this will increase the temperature about 6 per cent. If the machine would run normally with a 47½-deg. C. rise, for a current variation of 130 per cent, it would probably run with over 50-deg. C. rise. However, there is usually enough margin in a synchronous motor so that this is not of much importance.

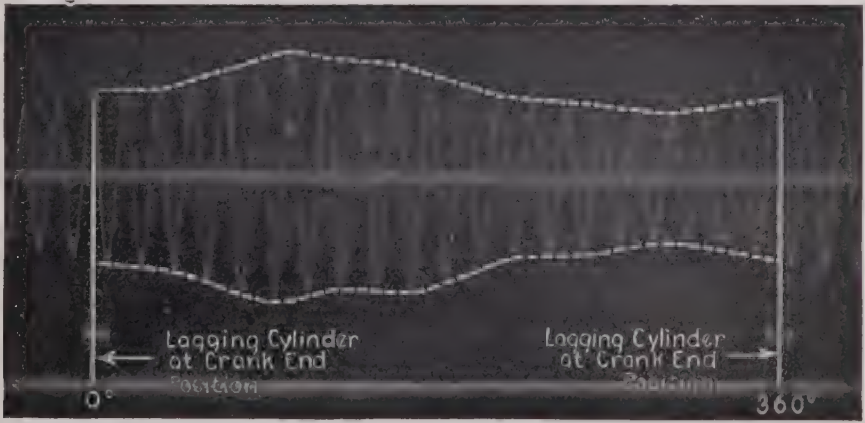

Fig. 1. Oscillogram of Load Current Variations of a Synchronous Motor Driving a Reciprocating Compressor

On the other hand, it is necessary to take special precautions to prevent a motor from shaking to pieces when the torque shifts several hundred times a minute from 35 per cent to 165 per cent.

Long before synchronous motors were used for driving ammonia compressors, they were built for old-fashioned, low-speed air compressors. When improper flywheels were furnished, some of these old motors, after several years' service, shook to pieces, after which new flywheels were furnished. A rough analysis of this past experience shows that whenever the current pulsation was less than 60 per cent, no trouble was experienced with motors shaking to pieces, whereas, in most of the cases of failure the current pulsations were in excess of 100 per cent. At the present time, whenever the author's company furnishes a synchronous motor for operation where the current pulsation will be over 100 per cent, special precautions are taken to stiffen the parts to withstand these added stresses. Due to these precautions and the general improvement in insulation, the few motors which have been sent out in the last few years for service with current pulsations around 120 per cent have given successful operation up to date.

(3) The lighting company is probably interested in current pulsation only from the standpoint of possible flicker of lights, damage to meters and voltage regulators, and interference with the general service to other customers.

During the same long experience with air and ammonia compressor motors, it has been noticed that in most of the cases where there has been complaint concerning flicker of lights the current pulsation has been greater than 60 per cent. The current pulsation itself does not cause the lights to flicker, but acting on the impedance of the line causes the voltage to go up and down. Fig. 3(3) shows the percentage voltage regulation which will just barely cause lamps to flicker. It will be noticed that if the voltage varies 400 times per minute, a quarter of a per cent variation will cause a barely perceptible flicker. If the variation is faster than 400 times a minute, the percentage can be slightly increased without causing flicker, or if it is slower than 400 the percentage can also be slightly increased. It should be borne in mind, however, that a certain amount of flicker does not seem to be objectionable. There are various places where the voltage is varying more than shown by this curve, and yet there has been no complaint about flicker. In these cases, it is usually only possible to see the flicker when special attention is called to the light striking a polished white wall.

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(3) This curve was drawn on June 28, 1921, by Willard C. Brown, of the National Lamp Works of the General Electric Company.

Where the synchronous motor is a large part of the load on the end of a long lighting feeder, it is sometimes necessary to restrict the current pulsation to considerably less than 60 per cent, in order to prevent flicker of lights. There was one case where 40 per cent current pulsation caused a flicker of lights on a long feeder. Another quite conspicuous case was that of a synchronous motor on the end of a three-mile, 2200-volt transmission line, consisting of No. 0 wire. A current pulsation of 40 per cent caused such objectionable flicker that the power company ordered the ice plant using the motor off its lines. Calculations showed that the current pulsation would have to be limited to about 7 per cent, in order to restrict the voltage variation within the limits of Fig. 3. A new flywheel was supplied in accordance with these calculations, and since that time there has been no complaint concerning the flicker.

Tests have shown that the modern, up-to-date watthour meter reads correctly, even on a pulsating load. Some of the older meters with heavier moving parts were not able to speed up and slow down quickly enough to follow the pulsating load. But even then, their indications were within about one per cent.

A case is known where an induction type voltage regulator was installed on a feeder where the current pulsation was excessive. It is the author's understanding that the regulator had to be removed because it could not follow the rapid variations in voltage.

Before leaving the question of the effect of current pulsation, it seems well to point out that sometimes flywheels are designed to give 60 per cent current pulsation with a two-cylinder, double-acting compressor. During the winter, the customer perhaps disconnects one of the cylinders. Unless the flywheel has been designed to take care of this arrangement, a current pulsation of over 100 per cent will probably result. The average current is 50 per cent. In these cases, the current and the torque of the motor reverses twice per revolution. The author has seen oscillograms which showed a reversal of 30 per cent current. Motors can be built for this service, but it seems an unreasonable requirement when one considers a 100-r.p.m. motor running with the torque reversing 200 times per minute from 130 per cent forward to 30 per cent backward.

Brief Outline of the History of the Various Methods of Calculating Flywheels

The fundamental theory of the calculation of flywheels for synchronous machinery direct-connected to reciprocating apparatus was worked out years ago, and has long been available in various mathematical books. R. E. Doherty and R. F. Franklin in their paper, "Design of Flywheels for Reciprocating Machinery Connected to Synchronous Generators or Motors," which was presented at the Annual Meeting of the American Society of Mechanical Engineers, December, 1920, especially mentioned Steinmetz, Berg, Astrom, Abbott, Slichter, Boucherot, and Hawkins and Wallace, in addition to giving a large bibliography of the various articles which have been published on flywheels.

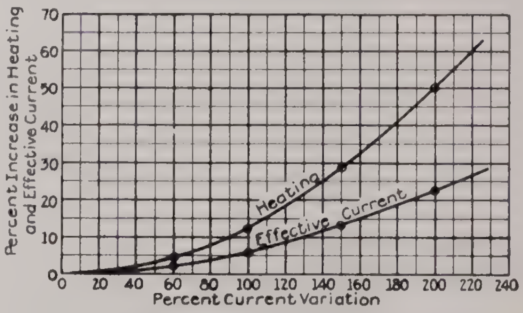

Fig. 2. Effect of Current Variation on Effective Current Values and Motor Heating

Among the earlier articles on the subject which are of particular interest are the following:

(1) "Coupling Flywheel Alternators in Parallel," by Paul Boucherot, in Vol. 1, of the Transactions of the International Electrical Congress of 1904, in St. Louis.

(2) Vol. 3 of "Leçons d'Électrotechnique Générale," by P. Janet, 1912.

Both of these authors give the correct theory, but their equations are left in difficult mathematical form, which prevented their ready adoption by practical engineers.

Due to the lack of reliable design constants and the apparent complexity of the correct mathematical equations, most practical engineers used a simpler but rather inaccurate method of calculation. The torque of the synchronous motor was assumed to be constant and exactly equal to the average torque of the compressor. The angular deviation from the position of uniform rotation was calculated directly from the crank effort diagram of the compressor and the inertia of the flywheel and rotating parts of the compressor and synchronous motor.

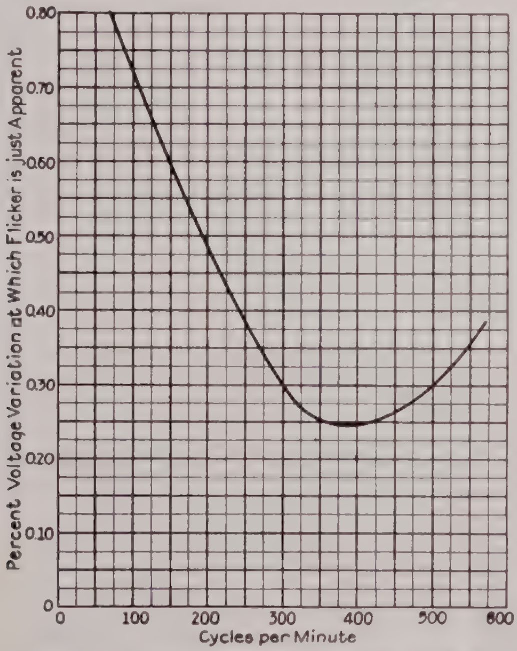

Fig. 3. Voltage Fluctuations Necessary to Cause Lamp Flicker at Various Periodicities

The errors in this method of calculation are thoroughly discussed in a paper by the author, in the November, 1922, GENERAL ELECTRIC REVIEW entitled, "Error Due to Neglecting Electrical Forces in Calculating Flywheels for Reciprocating Machinery Driven by Synchronous Motors."

It was realized that the constant torque method was not accurate and would not give the correct deviation, if the natural frequency of vibration due to the synchronizing torque of the motor and the inertia of the flywheel and rotating parts was close to one of the forced frequencies of the crank-effort diagram. But experience showed that if the angular deviation calculated from the crank-effort diagram was restricted to a certain limit and, if the natural frequency of vibration was at least 20 per cent different from the nearest forced frequency, successful operation would be obtained.

The limits of angular deviation for this old method of calculation were gradually increased from ± 2 electrical degrees to ± 3½ electrical degrees. This increase was made in steps of half a degree, from 2 to 2½ to 3 to 3½, and was largely based on experience.

The paper presented by Doherty and Franklin at the December, 1920, meeting of The American Society of Mechanical Engineers, was the first publication with which the present author is familiar, which showed oscillograph tests of an actual installation as a check on the correct theory of calculation.

But, even as late as 1920, this paper by Doherty and Franklin calculated angular deviation in electrical degrees. It was largely a scientific justification for the double limit in terms of 3½ electrical degrees deviation, neglecting the electrical forces, and 20 or 25 per cent differences between the natural frequency of vibration and the nearest forced frequency. However, in justifying these limits, Mr. Doherty pointed out that the real limit was current variation. The following quotation from the paper is of interest:

> "How much current fluctuation shall be accepted as reasonable and safe? One or two per cent is, of course, absolutely harmless. On the other hand, 100 per cent would obviously be out of the question. Considerations such as the possible voltage fluctuation, increased loss and heating, fatigue of materials, particularly the insulation, subjected to the incessant reversal of stress—these considerations must determine the allowable pulsation. While experience has perhaps not yet finally settled the matter, it now seems that the pulsation should never be greater than 50 to 60 per cent of normal current. This means that the total actual angular fluctuation during operation must be limited to the order of six to ten electrical degrees, that is, three to five degrees plus or minus deviation. . . ."

The paper also pointed out that in certain instances, if the angular deviation, as determined by the crank effort alone, did not exceed 3½ electrical degrees and the natural oscillating frequency was not within 25 per cent of any forced frequency, the actual angular deviation would not be more than plus or minus six degrees and the amplitude of current variation would be in the neighborhood of 50 or 60 per cent.

Appendix D of the paper by Doherty and Franklin contained a formula for angular deviation from the position of uniform rotation, as follows:

$$\theta=\sum\sqrt{\frac{a_m{}^2+b_m{}^2}{M_m{}^2+N_m{}^2}}\sin\left\{m\omega t+\arctan\left(\frac{N_m b_m-M_m a_m}{N_m a_m+M_m b_m}\right)\right\} \qquad (1)$$

Where θ = angular deviation in mechanical radians

$M_m = T_d m\omega$

$N_m = T_s - m^2\,\omega^2 I$

T_s = synchronizing torque per mechanical radian displacement

I = moment of inertia = $\frac{WR^2}{g}$

T_d = damping torque due to amortisseur winding per mechanical radian per second slip

ω = synchronous speed in mechanical radians per second

a_m and b_m = coefficients of the Fourier's series, representing the crank effort diagram of the compressor.

Shortly after the publication of Mr. Doherty's paper, it was decided to use the correct method of calculation and aim for a limit of 60 per cent current variation.

About that time, the De La Vergne Machine Company asked advice concerning a flywheel for a 40-pole 360-kv-a., 450-h.p. unity p-f., 180 r.-p.m., 440-volt synchronous motor, for connection to a two-cylinder, 15-in. diameter by 18-in. stroke, double-acting ammonia compressor with cranks at right angles. On March 4, 1921, a report was sent to the De La Vergne Machine Company that, by the correct method of calculation, no extra flywheel would be required and the current variation would be about 48 per cent. This was the first time that the lengthy method of calculation from Appendix D of Mr. Doherty's report had ever been applied to a problem arising in the regular routine of business.

Later tests on this machine showed a current pulsation of 53.6 per cent. A complete description of these tests is given in the article by the present author, entitled "Error Due to Neglecting Electrical Forces in Calculating Flywheels for Reciprocating Machinery Driven by Synchronous Motors," in the November, 1922, GENERAL ELECTRIC REVIEW.

Figs. 1 and 4 taken from page 697 of this article show the comparison of the calculated wave shape of the current variation and the envelope of the oscillogram obtained from test. It was quite a surprise to find how closely the shape, as well as the amplitude of the current pulsation, had been estimated.

The new method made it possible to recommend flywheels very much lighter than those which would have been required by the older system.

During the summer of 1921, from March to November, flywheels were calculated for various propositions and requisitions by this long and laborious method.

During the summer of 1921, there was a great deal of interest aroused in the general principle of relativity. A very homely application of this principle to equation (1) showed that the per cent current variation would be the same for two similar compressors of different sizes and speeds, if the constant

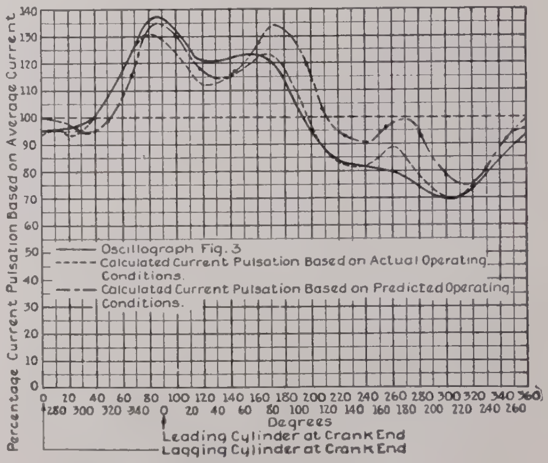

Fig. 4. Comparison Between Computed Variation Curves and Actual Oscillograph Records

$$x=WR^2\times\frac{S^4}{R\times hp.\times f}\times 10^{-8} \qquad (2)$$

and the ratio

$$\rho=\frac{\text{Indicated hp. of Compressor}}{\text{Rated hp. of Motor}} \qquad (3)$$

were the same for both installations where

S = r.p.m.

$$R=\frac{P_o}{KW}=\text{ratio}\ \frac{\text{Synchronizing torque expressed in kw. per electrical radian}}{\text{kw. rating of Motor.}}$$

f = Frequency of alternating current supply.

By November, 1921, quite a number of calculations had been made by the long method for different compressor installations. For each of these calculations, a curve of current variation against WR^2 had been plotted. With this principle of relativity in mind, all these data were replotted on one sheet, no longer using WR^2 as abscissa, but using a value of x given by equation (2), and no longer using per cent current variation as ordinate but a value of

$$y = \frac{\text{Current pulsation}}{\rho}$$

As a matter of historical interest, this original curve, Fig. 5, which was drawn on November 28, 1921, is reproduced here. It was found that the several dozen calculations for these three classes(4) of compressors, made during the summer of 1921, fell within the limits of the curves as shown. The wide variation in the curves for Class 2, which originally was thought to be due to the ratio of connecting rod length to crank length from $l = 4.38$ to $l = 6.05$, was found later to be an error due to the use of a wrong crank effort diagram. For compressors of this class (No. 2), the value l does not cause so much variation in the curves as does Q, which is the function of the weight of reciprocating parts.

These curves were immediately put into use in the estimating of proper flywheels, in order to speed up the service on propositions and requisitions. At the same time, further calculations were made to check up the accuracy of the curves. Further experience showed that other parameters were required in addition to l, the ratio of connecting rod length to crank length. For instance, the weight of reciprocating parts was found to make quite a difference in compressors of Class 2.

Other curves were also prepared for compound compressors and compressors operating under unbalanced conditions.

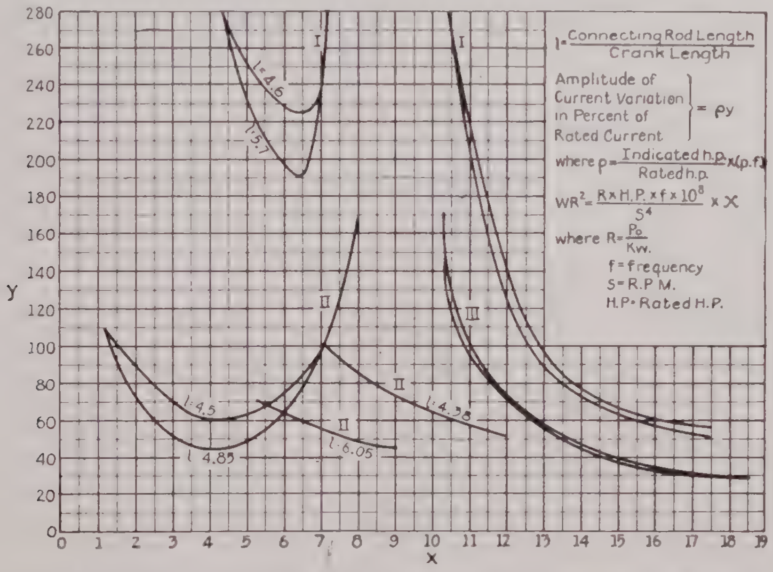

Fig. 5. Curves Used in Expediting the Computations of Compressor Flywheels

After the A. S. R. E. and the Electric Power Club had recommended that the calculations be made for normal summer pressures with 20-lb. suction and 185-lb. discharge and maximum pressures with 30-lb. suction and 215-lb. discharge, it was decided to recalculate all these curves for these conditions.

Due to the rush of work, these recalculations have only been completed for the three main classes of compressors. E. E. Johnson, of the General Electric Company, has made a very interesting set of curves for these three classes of compressors with the various parameters. These will be shown and discussed in Part II.

(To be Continued)

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(4) Class 1 Single cylinder, double acting.
Class 2 Two cylinder, single acting.
Class 3 Two cylinder, double acting.

A Study of Crystal Structure and Its Applications

PART VI*

THE POWDER METHOD OF CRYSTAL ANALYSIS

By Dr. Wheeler P. Davey

Research Laboratory, General Electric Company

In the preceding installments of this series on Crystal Structure Analysis, the author has explained the theory and the technique of the Laue and Bragg methods of x-ray analysis. In both of these methods the specimen used was a single crystal, often difficult or impossible to obtain. The author now takes up the so-called "Powder" method, which has the advantage of analyzing the unknown crystal in a finely divided form. Thus, by employing the substance as fillings or powder, this method is capable of handling almost any substance whose atoms normally have a crystalline arrangement. The procedure, together with the interpretation of its results, is given in the present article and in those to follow.—Editor.

The Powder Method

This method was devised independently by A. W. Hull(50) and by P. Debye and P. Scherrer.(51) Just as the Laue and Bragg methods were named after the men who first employed them, so in naming this method an attempt was made to honor those who originated it by calling it the "Hull-Debye-Scherrer" method. The awkwardness of this name has been responsible for the widespread use of the descriptive title "Powder Method." This method uses a beam of essentially monochromatic x-rays as does the Bragg method, but instead of using perfect single crystals, it uses crystals which have been crushed to such a fine powder that the fragments have a random or chaotic orientation. Such a powder requires no rotation, for, since every atomic plane is present in every possible orientation, there must be some individuals from each family of planes which are oriented at the correct angle to diffract the monochromatic x-ray beam. If the volume of powder used is large enough and the fragments are sufficiently small, there will be, for any given family of planes, many individuals correctly oriented, so that the combined effect for any one plane is much the same as might be expected from a large single crystal having the same orientation. Experimentally it is found that in most cases the powder is fine enough if it will go through "200-mesh"(52) bolting cloth and that it is of sufficient amount if it will fill a cylindrical container about ¾ mm. in diameter and about 10 mm. long, i.e. if the total volume is about 5 cubic mm. Since every atomic plane in the powdered crystal has some representatives at the correct angle for diffraction, the whole diffraction pattern may be photographed simultaneously.

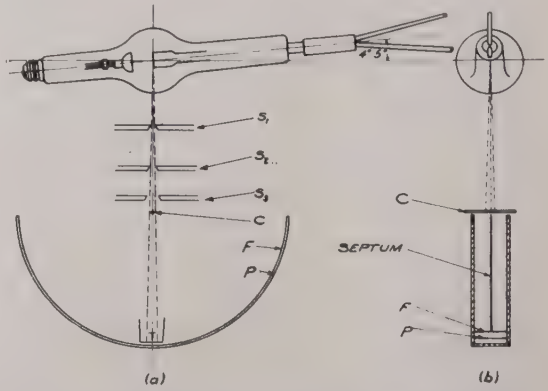

Fig. 36. Typical Apparatus for the Powder Method
(a) View from top (b) View from side

The powder method may be used with any crystalline substance. It is the only method which can be used with that large class of substances which cannot be obtained easily in the form of perfect crystals of appreciable size. This class includes not only most metals and their alloys, but also a large number of compounds. For instance, the writer wished to study the crystal structure of calcium selenide, CaSe. As this was not an article of

(50) A. W. Hull, Paper before *Am. Phys. Soc.* Oct., 1916. *Phys. Rev.* *9*, 84, 564 (1917); *10*, 661 (1917).

(51) P. Debye and P. Scherrer, *Nachr. d. Kgl. Ges. Wiss. Gottingen.* (1915-16) *Phys. Zeit*, *17*, 277 (1916) *18*, 291, 301 (1917).

[52] The openings in such cloth are of the order of 0.06 mm.

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*References made to material hitherto published in this series of articles may be readily located from the following table:

Issue	Figs.	Equations	Tables	Footnotes
Part I, Nov., 1924; p. 742	1 and 2	1 to 16	1 and II	1 to 21
Part II, Dec., 1924; p. 795.	3 to 10	17 to 32	III	22 to 27
Part III, Feb., 1925; p. 129	11 to 22	33 to 37	IV	28 to 42
Part IV, Apr., 1925; p. 258	23 to 28	38 to 41	None	43 to 48
Part V, May, 1925; p. 342	29 to 35	None	None	49

commerce, it had to be made for the occasion by heating weighed lumps of metallic calcium and selenium in a hard glass tube which had previously been evacuated and sealed off. The reaction took place with explosive violence, shattering the glass tube to small bits. These bits were gathered, and on the concave side of each was found a thin layer of dark scale. This was scraped off and found to be composed of crystals of CaSe. Crystallization had taken place during the time in which the explosion took place, thus giving rise to extremely minute crystals. They were examined by the powder method with complete success, although they were obviously quite unsuited for either the Laue or Bragg methods.

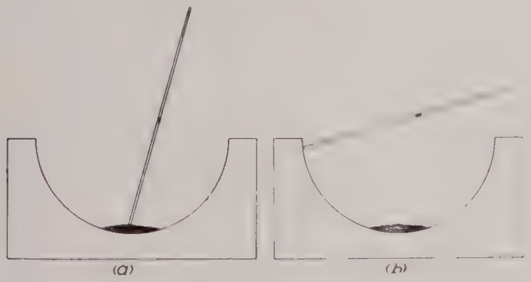

Fig. 37. Filling a Specimen Tube

(a) Beginning of stroke (b) End of stroke

Experimental Technique of the Powder Method

A typical arrangement of x-ray tube, slits and specimen is shown diagrammatically in Fig. 36. Slits S_1 and S_2 serve to define the x-ray beam. S_3 cuts off any diffraction pattern from the crystals on the edge of S_2. The specimen of powdered crystal is at *C*. In the type of apparatus illustrated, the width of the specimen is less than that of the x-ray beam, so that the effective width of the beam is determined by the width of the specimen. The diffraction pattern is recorded on the photographic film *P*. The filter *F* renders the rays practically monochromatic (see Part IV). The trap *T* not only prevents over-exposure from the undeviated beam, but also by its shape prevents fogging the film by rays scattered by the trap from the primary beam. A septum in the film-holder allows two diffraction patterns to be taken on the same photographic film.

Ordinarily if the specimen is a salt or some other brittle type of crystal, it is crushed in an agate mortar. If the specimen is a metal it may be reduced to filings using only light pressure on a very fine, clean file. The powder or filings are then sieved through a clean 200-mesh silk bolting cloth. This powder may be mounted in any of several ways. Probably the most common method is to fill it into a thin walled glass tube of about 0.6 mm. internal diameter. Care must be taken that the glass contains only elements of low atomic weight. Lead-free lime glass, such as is made for x-ray bulbs by the Vineland Flint Glass Works (Vineland, N. J.), or pyrex glass tubes, are suitable. They may be drawn down easily from larger sized tubing. Corning glass, known as *707 BM*, from the Corning Glass Works (Corning, N. Y.) is especially good. Ordinary hard glass usually contains a little lead and is too opaque to the x-rays. In some cases celluloid tubes might be used to advantage.

These tubes may be loaded rapidly and with little danger of breakage by means of the following technique. (1) A plug of cotton is pushed into the tube to a point midway between the ends, using as a ramrod a piece of 10-mil wire of platinum, molybdenum, tungsten, or other non-corrosive material. The plug should not be longer than the width of the septum in the film-holder (see Fig. 36 *b*). (2) The open end of the tube is scraped along the bowl of the mortar containing the crushed crystal, starting at the bottom and ending at the top (see Fig. 37, *a* and *b*). (3) The tube is then held vertically between the thumb and index finger of one hand and the thumbnail is tapped with a pencil. This causes the powder to drop into the tube. (4) These operations are repeated until enough powder has been collected to extend from the septum to a point beyond the edge of the x-ray beam. A second piece of cotton is then inserted to keep the powder in place. (5) The whole procedure is repeated in loading some other crystal into the other half of the specimen-tube. The first powdered crystal to be loaded is some substance used as a comparison standard, usually NaCl ($a = 2.814$ A) which is the secondary standard for interplanar distances.(11) The second substance is the one under investigation. The two ends of the tube are then plugged with sealing wax with the aid of an electrically heated nichrome hairpin, and an identification tag is waxed on. Care must be taken that no sealing wax is on that part of the tube exposed to x-rays, for in such a case the inorganic filler in the wax will produce a diffraction pattern of its own. If the powdered crystal is slightly hydroscopic the agate mortar must be kept heated to about 100 deg. C. on a hot plate during the loading operation. A full-size diagram of the loaded tube is shown in Fig. 38.

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(11) General Electric Review, *27*, p. 745, Nov., 1924.

It is often advisable to anneal the sieved powder. The act of crushing or filing introduces strains into many crystals, thus producing "warped planes" of atoms. The effect of warping on the intensity of the diffracted beam is not very marked for those planes which are farthest apart, but becomes quite serious for those planes in the crystal whose interplanar distance is small. Besides reducing the efficiency of diffraction at large angles, warping decreases the resolving power of the crystal fragments. It has already been explained in Part IV that the nearest convenient approach to monochromatic x-rays gives a beam containing two wavelengths, called α_1 and α_2, which differ from each other by less than one per cent. Each of these is diffracted by the crystal powder independently of the other, so that if the angle of diffraction, θ, is large enough (in the case of Mo rays this angle is about 21 deg. for a specimen in a cylindrical container about 0.6 mm. in diameter) each "line" of the diffraction pattern should be a doublet if the crystal is composed of true planes of atoms. If the crystal fragments in the powder have warped planes, each line of these doublets is widened out until the lines of the doublet tend to become merged into a single line of rather hazy outline. The total energy of the diffracted beam from the warped planes is spread out over a larger area of the photographic film, so that the "line" is less black on the film than it otherwise would be. This gives the effect of a decrease in efficiency of diffraction in addition to the real loss just mentioned. This may be illustrated by an experiment with tungsten. A tungsten incandescent lamp was burned for four hours at its rated voltage in order to anneal the filament thoroughly. The filament was then removed and crushed to a powder in an agate mortar. Half of this powder was then re-annealed in hydrogen at the same temperature as before in order to remove the strains produced by crushing. Diffraction patterns of the two portions were taken side by side on the same film. They are shown in Fig. 39.

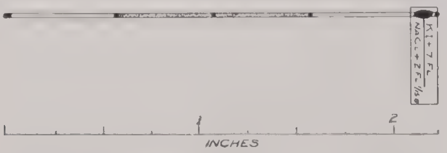


Fig. 38. Diagram of Filled Specimen Tube

While the primary beam is traversing the specimen it suffers absorption. Still further absorption occurs in each of the diffracted beams on their way out from the specimen. If the specimen is mounted as shown in Fig. 36, the optimum thickness of crystalline material is approximately

$$t=\frac{1}{\mu} \tag{42}$$

where μ is the coefficient of absorption of the crystal for the wavelength of x-rays used.(50) This may be shown as follows:

If the original intensity of the incident primary beam is I_0, the intensity after passing through a distance x is reduced to

$$I_1=I_0\,e^{-\mu x}$$

The initial intensity, $d\,I_2$, of a diffracted beam from a layer of thickness dx at a distance x below the surface must be proportional to dx and to I_1, so that

$$d\,I_2=kI_1\,dx=kI_0\,e^{-\mu x}\,dx$$

The path of the diffracted beam to the surface of the crystalline material may be expressed approximately as $(t-x)$ where t is the thickness of the specimen in the direction of the incident beam. The intensity I_3 of the emergent diffracted beam is therefore approximately

$$\begin{aligned}I_3&=\int_0^t kI_0\,e^{-\mu x}\,e^{-\mu(t-x)}\,dx\\&=\int_0^t kI_0\,e^{-\mu t}\,dx\\&=kI_0\,t\,e^{-\mu t}\end{aligned}$$

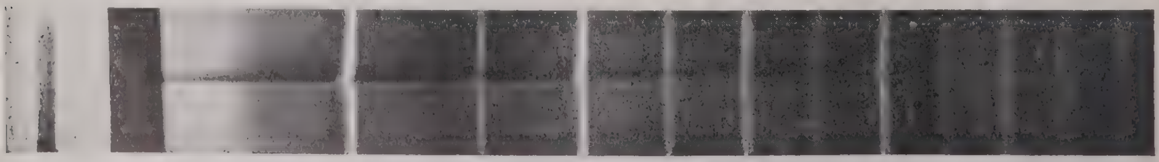
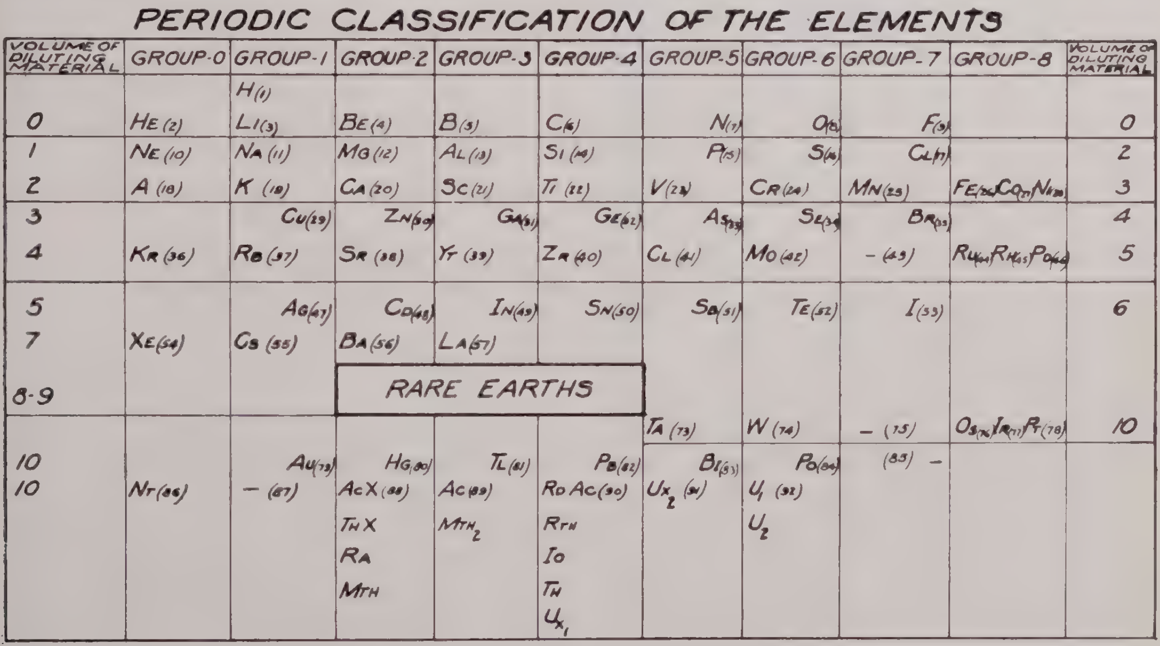


Fig. 39. Diffraction Pattern of Strained (above) and Unstrained Tungsten (below)

This will be a maximum if $\frac{d\,I_3}{d\,t} = 0$, i.e. when

$$t = \frac{1}{\mu}$$



PERIODIC CLASSIFICATION OF THE ELEMENTS

VOLUME OF DILUTING MATERIAL	GROUP-0	GROUP-1	GROUP-2	GROUP-3	GROUP-4	GROUP-5	GROUP-6	GROUP-7	GROUP-8	VOLUME OF DILUTING MATERIAL
		H (1)								
0	He (2)	Li (3)	Be (4)	B (5)	C (6)	N (7)	O (8)	F (9)		0
1	Ne (10)	Na (11)	Mg (12)	Al (13)	Si (14)	P (15)	S (16)	Cl (17)		2
2	A (18)	K (19)	Ca (20)	Sc (21)	Ti (22)	V (23)	Cr (24)	Mn (25)	Fe (26) Co (27) Ni (28)	3
3		Cu (29)	Zn (30)	Ga (31)	Ge (32)	As (33)	Se (34)	Br (35)		4
4	Kr (36)	Rb (37)	Sr (38)	Yt (39)	Zr (40)	Cb (41)	Mo (42)	– (43)	Ru (44) Rh (45) Pd (46)	5
5		Ag (47)	Cd (48)	In (49)	Sn (50)	Sb (51)	Te (52)	I (53)		6
7	Xe (54)	Cs (55)	Ba (56)	La (57)						
8-9			RARE EARTHS							
						Ta (73)	W (74)	– (75)	Os (76) Ir (77) Pt (78)	10
10		Au (79)	Hg (80)	Tl (81)	Pb (82)	Bi (83)	Po (84)	(85) –		
10	Nt (86)	– (87)	AcX (88) ThX Ra MTh	Ac (89) MTh_2	RdAc (90) RTh Io Th Ux_1	Ux_2 (91)	U_1 (92) U_2			

Fig. 40. Empirical Dilutions of Powdered Material

It is obviously not convenient to use specimen tubes of different diameter for different crystalline materials. The same effect may be obtained, however, using tubes of constant diameter, by diluting the powdered crystal with some amorphous material of low opacity to the x-rays. Gum tragacanth is sufficiently amorphous for this purpose. For many crystalline materials the diffraction pattern is so strong in comparison with that from cellulose that cornstarch or flour may be used as a diluent. In general, the higher the atomic number, the greater is the coefficient of absorption of the crystal. For this reason, from the standpoint of equation (42), crystals composed of elements of high atomic number should be very greatly diluted. There are, however, practical limits to the amount of dilution, for a point is soon reached where there are not enough crystal fragments present in the material which can be packed into a specimen tube to give a truly chaotic orientation. Fig. 40 gives an empirical schedule, used by the writer, for diluting powdered crystals. At each end of the horizontal rows of Fig. 40 will be found a number. This represents the number of volumes of diluting material to be mixed with one volume of an element at that end of the row. If the crystal is a compound, the weighted average is taken of the dilutions for the elements in the compound, the weights being proportional to the number of atoms of the element in the chemical formula for the compound.

In certain cases the glass specimen-tube may be dispensed with. If the specimen is not hydroscopic and is not readily oxidized in the air, the powdered crystal may be mixed with an amorphous adhesive such as gum tragacanth and pressed up into a thin slab having a flat straight edge. This slab may then be mounted with its edge at *C*, Fig. 41, so as to make a very slight angle with the primary beam. The edges of the lines in the diffraction pattern are sharpened if some opaque amorphous material like lead glass is used as a backing. In some cases it is possible to substitute for the slab and lead glass a strip of thin cardboard which has a layer of the powder stuck on its edge. The crystals of mechanically worked metals are usually quite small. If the specimen to be examined is a thin sheet of metal having a straight edge it may be mounted in the same manner as the slab described above. Most metals are sufficiently opaque to the x-rays used in crystal analysis so that the lead glass "backing" is unnecessary. If the metal is in the form of a thin wire it may be stretched out in the path of the beam, so as to take the place of the specimen tube of Fig. 36. This is one of the most desirable methods of mounting a specimen when no other diffraction pattern is to be taken on the same film for purposes of comparison. If a comparison pattern is desired, the wire and the comparison-standard may be mounted along the same straight line on the edge of an amorphous holder such as a slab of pressed gum tragacanth or a sheet of glass, or the wire and the comparison-standard may be inserted in opposite ends of a glass or celluloid specimen-tube. If the wire is of very fine diameter it is best to use several lengths side by side. For 5-mil wire six or seven lengths are sufficient.

St. John(53) has applied the principal of the "Seemann slit"(54) to powdered crystals. The specimen is a pressed slab of powdered crystal diluted with gum tragacanth. Since the reciprocal of the dilution is made proportional to the thickness, t, of equation (42) the dilution must be roughly proportional to the coefficient of absorption, μ. An x-ray beam passes a pair of slits, (Fig. 42) and falls upon the specimen-slab. A narrow slit adjacent to the slab permits x-rays to pass to the photographic film. Each of the diffracted beams comes from a different part of the slab, so that homogeneity of the slab is essential. It is important too that the x-ray beam be used only at a small angle from the face of the target so that all parts of the slab are irradiated uniformly. For any given "line" in the diffraction pattern the effect is the same as if all the crystalline material in the path of the x-rays composing that "line" had been crowded up into the specimen tube of Fig. 36. The advantage of the scheme is that although the glass specimen tube is eliminated, thus avoiding variations in the general fog on the photographic film caused by variations in the thickness of the glass wall of the specimen-tube, the slits cause the lines on the diffraction pattern to be very clean and sharp without the necessity of preparing a specimen with a narrow edge. The scheme is, of course, as unsuited to hydroscopic substances or to subtances which tend to oxidize in the air, as is the scheme of Fig. 41.

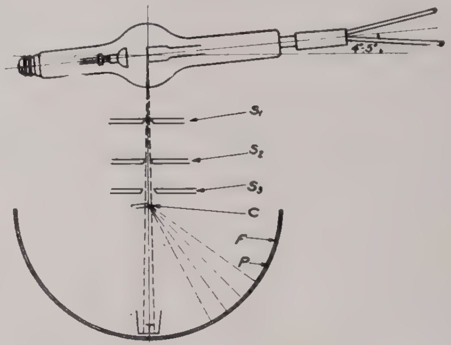


Fig. 41. Powder Method Applied to a Pressed Block

The Diffraction Pattern and Its Interpretation

It is inherent in the powder method that all the families of atomic planes in the specimen send out their diffracted beam simultaneously. A single photographic film may therefore be made to record the whole diffraction pattern, or as much of it as may be desired. Each family of planes in the powdered crystal produces a line on the film for its first-order diffracted beam and additional lines for such other orders of diffraction as may be physically possible, provided only that $\frac{n\lambda}{2d}$ is less than unity, see equation (1). The photographic record of the diffraction pattern is therefore a series of lines whose angular distances from the "zero line" (photographic

TABLE V

DISTANCE BETWEEN ROWS IN A SIMPLE SQUARE (TWO-DIMENSIONAL) LATTICE

Distance Between Rows	Ratio From Experiment (25.0 = 1)	Ratio Calculated for Simple Square	Miller Indices For Rows of Simple Square
25.0 ft.	1.00	1.00	1, 0
17.7	0.71	0.707	1, 1
11.2	0.45	0.447	2, 1
7.9	0.32	0.316	3, 1
6.9	0.28	0.277	3, 2
6.0	0.24	0.242	4, 1

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[53] A. St. John, *Am. Ass. Adv. Sci.* Jan. 1, 1925.

[54] H. Seemann, *Phys. Zeit.* *20*, 169 (1919).

record of the undeviated beam) are characteristic of the various interplanar spacings in the crystal. From these angular distances, and the wavelength of the x-rays, the interplanar spacings may be calculated at once from equation (1).

Knowing the interplanar spacings, it is possible, at least in the case of the simpler crystal systems, to find by systematic cut-and-try methods an arrangement of atoms in space which will account for the observed interplanar distances. The situation may be visualized by the following illustrations in two dimensions. If the trees of an orchard are planted according to some systematic geometrical scheme, they will appear to be in rows whose direction and distance apart will depend upon the position of the observer with respect to the orchard. Now suppose that the reader had never seen the orchard, but had been supplied with data giving the distance apart of these various rows of trees, and suppose that it is required to draw a map to scale showing the positions of the trees in the orchard. It would be necessary to list the data in a column in the order of the size of the numbers, starting with the largest number at the top of the column. In a parallel column a corresponding list would be made of the ratios of the several distances to the largest distance, as in Table V. Some geometrical configuration of trees must now be assumed and the ratios of distances required by that configuration must be compared with the tabulated ratios. If they do not agree, a new configuration must be assumed and its ratios compared with those listed from the data. The data of Table V are from an orchard set out so that the trees are at the corners of imaginary squares, for such a configuration gives ratios of 1, $1/\sqrt{2}$, $1/\sqrt{5}$, $1/\sqrt{10}$, $1/\sqrt{13}$, $1/\sqrt{17}$, etc., which are identical with the ratios of the tabulated data. It is evident that the side of the imaginary unit-square is 25 feet long.

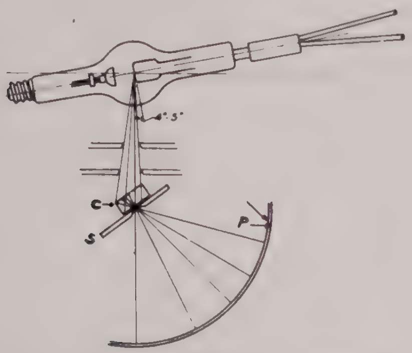

Fig. 42. St. John's Application of a Seemann Slit

Suppose the distances between rows had been those listed in the first column of Table VI. Certain of the ratios in the second column are identical with those of Table V. Such an accidental agreement cannot be taken to mean that the plan of the orchard of Table VI is a simple square, for if *every* experimental ratio is not duplicated within the precision of the data in the table of calculated ratios, the solution cannot be valid. Trial shows that *every* experimental ratio is duplicated in the ratios calculated for a centered square. In this configuration some of the trees are at the corners of imaginary squares and additional trees are at the centers of these squares so that the configuration is that of a "figure five" on dice. The actual distances in Table VI may be accounted for if the side of the unit-square is 25 feet long. If the side of the square is taken as the unit of measure, the experimental distances give the ratios listed in the fourth column. The corresponding calculated ratios are given in the fifth column. A comparison of the fifth column of Table VI with the third column of Table V shows that the effect of the additional trees has not been to produce rows in new directions in the orchard, but only to cut in half the distances between those rows which have one even Miller index.

TABLE VI

DISTANCE BETWEEN ROWS IN A CENTERED-SQUARE (TWO-DIMENSIONAL) LATTICE

Distances Between Rows	Ratio from Experiment 17.7 = 1.00	Ratio Calculated for Centered Square	Ratio from Experiment 25.0 = 1.00	Ratio Calculated for Centered Square	Miller Indices for Rows of Centered Square
17.7 ft.	1.00	1.00	0.71	0.707	1, 1
12.5	0.71	0.707	0.50	0.500	1, 0
7.9	0.45	0.447	0.32	0.316	3, 1
5.6	0.32	0.316	0.22	0.223	2, 1
3.4	0.19	0.195	0.14	0.138	3, 2
3.0	0.17	0.171	0.12	0.121	4, 1

TABLE VII: INTERPLANAR SPACINGS IN TYPICAL CUBIC CRYSTALS

Miller Indices, h, k, l	$h^2+k^2+l^2$	Number of Families of Planes	INTERPLANAR SPACINGS, INCLUDING THE FICTITIOUS SPACINGS FOR VARIOUS ORDERS OF DIFFRACTION, n=2, n=3, - - - - - -			
			Simple Cube	Body-centered Cube	Face-centered Cube	Diamond Cube
100	1	3	1.00			
110	2	6	0.707	0.707		
111	3	4	0.577		0.577	0.577
100	4	3	(n=2) 0.500	0.500	0.500	
210	5	12	0.447			
211	6	12	0.408	0.408		
110	8	6	(n=2) 0.354	(n=2) 0.354	0.354	0.354
221	9	12	0.3333			
100	9	3	(n=3) 0.3333			
310	10	12	0.3160	0.3160		
311	11	12	0.3014		0.3014	0.3014
111	12	4	(n=2) 0.2885	0.2885	(n=2) 0.2885	
320	13	12	0.2774			
321	14	24	0.2672	0.2672		
100	16	3	(n=4) 0.2500	(n=2) 0.2500	(n=2) 0.2500	0.2500
410	17	12	0.2423			
322	17	12	0.2423			
411	18	12	0.2358	0.2358		
110	18	6	(n=3) 0.2358	(n=3) 0.2358		
331	19	12	0.2292		0.2292	0.2292
210	20	12	(n=2) 0.2234	0.2234	0.2234	
421	21	24	0.2180			
332	22	12	0.2132	0.2132		
211	24	12	(n=2) 0.2040	(n=2) 0.2040	0.2040	0.2040
430	25	12	0.200			
100	25	3	(n=5) 0.200			
431	26	24	0.1960	0.1960		
510	26	12	0.1960	0.1960		
511	27	12	0.1923		0.1923	0.1923
111	27	4	(n=3) 0.1923		(n=3) 0.1923	(n=3) 0.1923
520	29	12	0.1856			
432	29	24	0.1856			
521	30	24	0.1826	0.1826		
110	32	6	(n=4) 0.1766	(n=4) 0.1766	(n=2) 0.1766	(n=2) 0.1766
530		12		0.1714		
433		12		0.1714		
531		24			0.169	0.169
100		3		(n=3) 0.167	(n=3) 0.167	
221		12		0.167	0.167	
611		12		0.1621		
532		24		0.1621		
310		12		(n=2) 0.1580	0.1580	0.1580
533		12			0.1525	0.1525
311		12		0.1507	(n=2) 0.1507	
631		24		0.1474		
111		4		(n=2) 0.1442	(n=4) 0.1442	(n=4) 0.1442
110		6		(n=5) 0.1414		
710		12		0.1414		
543		24		0.1414		
711		12			0.1400	0.1400
551		12			0.1400	0.1400
320		12		0.1387	0.1387	
211		12		(n=3) 0.1360		
552		12		0.1360		
721		24		0.1360		
321		24		(n=2) 0.1336	0.1336	0.1336
730		12		0.1312		
553		12			0.1301	0.1301
731		24			0.1301	0.1301
732		24		0.1270		
651		24		0.1270		
100		3		(n=4) 0.1250	(n=4) 0.1250	(n=2) 0.1250
741		24		0.1230		
811		12		0.1230		
554		12		0.1230		
733		12			0.1222	0.1222
410		12		0.1212	0.1212	
322		12		0.1212	0.1212	

The interpretation of the diffraction pattern of a powdered crystal is much like the foregoing illustration except that there are three dimensions to be considered instead of two, and the data include fictitious distances d/n caused by lines in the diffraction pattern corresponding to the 2nd, 3rd, etc., orders of diffraction. In the cubic system it is easy with the aid of equation (18) to make reference tables, such as Table VII,(50) of interplanar distances taking the side of the unit-cube as the unit of length. The fictitious distances are listed in the table as though they actually existed, so that the table corresponds to all the interplanar distances calculated from the diffraction pattern just as truly as Tables V and VI correspond to all the distances measured in the orchards. An inspection of Table VII shows that the pattern for a simple cubic crystal contains every possible line which can be produced by a crystal having cubic symmetry. When the crystal structure is made more complicated by placing additional atoms in symmetrical positions in the simple cube without changing the dimensions of the cube, the effect is not to add more lines but to wipe out certain lines from the simple cubic pattern. This is brought out in Fig. 43 which is plotted from Table VII. The actual diffraction patterns differ from those of Fig. 43 in that they include the sine law of equation (1).

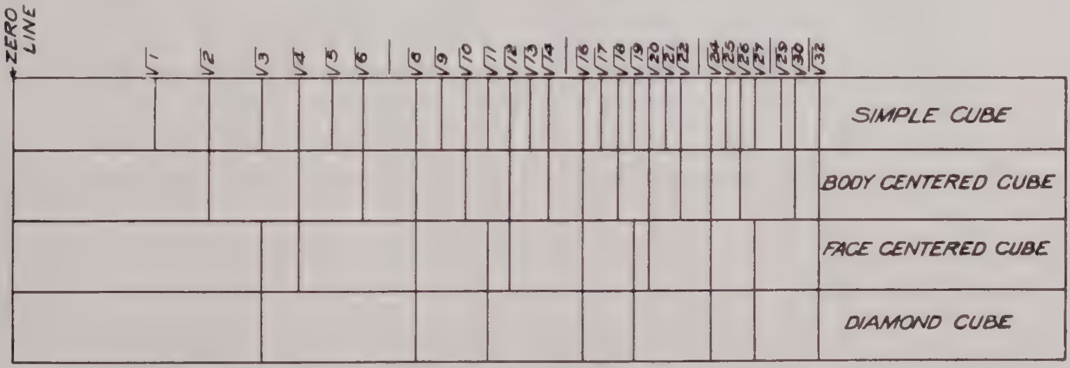

Fig. 43. Effect on Diffraction Pattern of Complicating the Crystal Structure

Equation (18) shows that each spacing for a simple cube is the reciprocal of the square root of the sum of three squares. These spacings therefore decrease in regular fashion for the first six lines of the diffraction pattern. There is, however, no line corresponding to $1/\sqrt{7}$ for no three squares can add up to 7. Similar breaks may be found at $1/\sqrt{15}$, $1/\sqrt{23}$, $1/\sqrt{28}$, etc., If therefore a diffraction pattern is found to have six lines regularly spaced, followed by a vacant place where the seventh line might be expected, it should be tested quantitatively at once to see if the ratios of spacings correspond to those of a simple cube. The spacings for the first six planes of a body-centered cube decrease in a regular way like those of a simple cube. In fact if, in Table VII, instead of using as a unit of measure the side of the unit-cube we had used the largest interplanar spacing calculated from the diffraction pattern (the 1 1 0 planes) we should have found exactly the same ratios as in the simple cube. The fundamental reason for this is that, for the body-centered cube, the numerator of equation (18) is unity only when the denominator is the square root of an even number. The diffraction pattern of a body-centered cube differs markedly, however, from that of a simple cube in that there is no break in the regularity of spacing of the lines until after the 13th line. The diffraction pattern of a face-centered cube has the first nine lines grouped so as to form three repetitions of "a pair followed by a single line." The tenth line, corresponding to the spacing $1/\sqrt{26}$, would be the first line of the next pair except that the second line of the pair would correspond to a spacing $1/\sqrt{28}$ which cannot exist. The sequence of "pair and one" is continued for three more groups after which it is broken up again by missing lines. The diffraction pattern of a diamond cube consists of a single line followed by a succession of pairs.

Graphical Methods of Interpretation

The quantitative examination of the diffraction pattern of a cubic crystal is easiest made with the aid of a slide rule. If the slide of the slide rule is turned so that the numbers are up-side-down, and the ends of the scales are made to register with each other (Fig. 44), it will be found that readings on the lower scale of the body of the slide rule are opposite the reciprocals of their squares on the inverted slide. If the slide is pushed along, any two readings on the lower scale of the body of the rule have the same ratio as the reciprocals of the square roots of the corresponding readings on the lower (adjacent) scale of the inverted slide. The interplanar distances of a crystal, as calculated from the diffraction pattern with the aid of equation (1), are therefore plotted on the lower scale of the body of the slide rule, using a soft lead pencil. The interplanar distances usually measured from the diffraction pattern range for most crystals from 2 or 3 A down to about 0.6 or 0.7 A. At 1.00 A the plot runs off the left-hand edge of the scale and must be continued at the right-hand end. The inverted slide is pushed along until "1" is opposite the pencil mark corresponding to the greatest interplanar distance. Suppose the next pencil mark is found opposite "2," the next opposite "3," etc. Taking note of the reading on the slide which is opposite 1.00 at the left-hand end of the fixed scale, move the slide back until this reading is opposite 1.00 at the right-hand end of the fixed scale (see Fig. 45). If *all* the remaining pencil marks also come opposite integers on the slide, the crystal is simple cubic, for its interplanar distances have the same ratios as those listed in the fourth column of Table VII. If an exact match is not obtained the slide is moved back until "2" on the inverted slide is opposite the pencil mark corresponding to the greatest interplanar distance. Then if *all* the pencil marks are opposite even numbers on the inverted slide, the crystal is body-centered cubic. If an exact match is still not found the slide is moved back until "3" on the inverted slide is opposite the first pencil mark, and the pattern, as plotted out on the body of the rule, is examined to see whether every pencil mark is opposite an integer on the inverted slide. If so, a comparison with the ratios of Table VII will show whether the diffraction pattern is characteristic of a face-centered or of a diamond cube. A similar procedure may be employed for still other types of cubic crystals. In all cases if an exact match is obtained within the limits set by the accuracy of the data, the reading on the lower scale of the body of the slide rule opposite "1" on the slide is the length in Angstrom units (10^{-8} cm) of the edge of the unit cube. It is important that the match be exact within the precision of the experimental data. If any lines in the experimental diffraction pattern are unaccounted for, either the solution is invalid, or it must be shown that the specimen consists of a mechanical mixture of two crystals such that every line is accounted for.

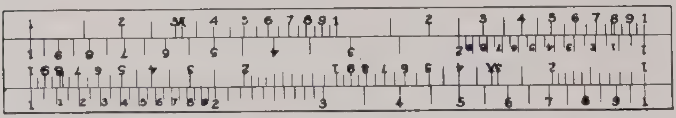

Fig. 44. Slide Rule Arranged for Quantitative Study of Diffraction Patterns of Cubic Crystals

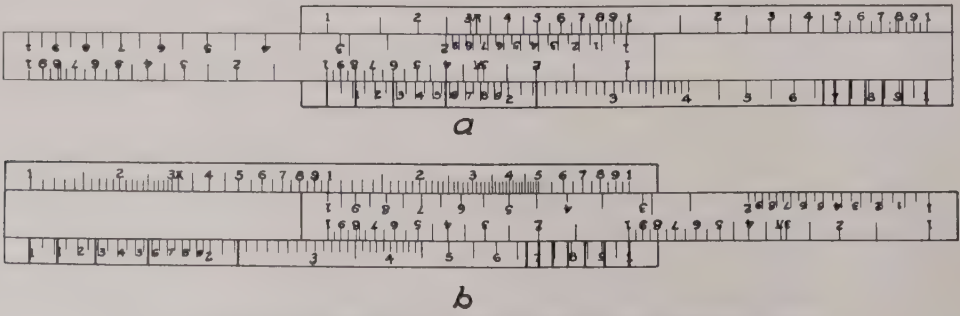

Fig. 45. Slide Rule Marked with a Body-centered Cubic Diffraction Pattern

(*a*) Slide at left-hand end (*b*) Slide at right-hand end

The usefulness of the slide rule in the solution of diffraction patterns of cubic crystals is due to the fact that the distances engraved on the inverted slide are proportional to the logarithms of successive values of *d* in equation (18). Since the scale on the body of the slide rule on which the

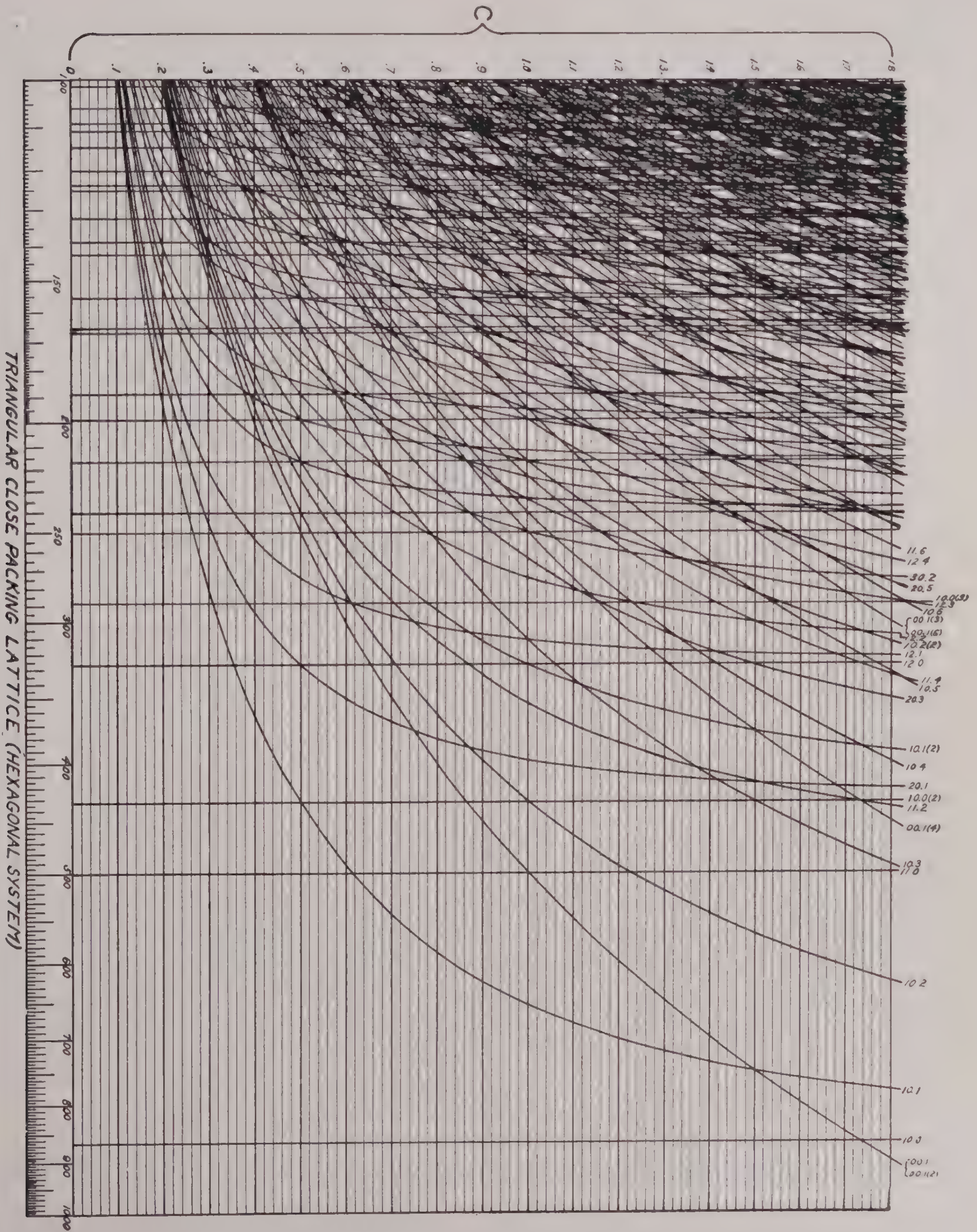

Fig. 46. Semi-logarithmic Chart for the Solution of Diffraction Patterns of Triangular Close-packed Lattices

experimental interplanar distances are plotted is also logarithmic, a direct comparison can be made between the two sets of ratios without further reference to the absolute values of the interplanar distances. This principle was used by the writer⁽⁵⁵⁾ in developing a series of semi-logarithmic charts for the rapid solution of the diffraction patterns of crystals belonging to the tetragonal and hexagonal systems. The logarithms of *d* from equations (19) and (28) were plotted as functions of the axial ratio, *C*. For any given value of *C* the lines of the chart have the same relation to the theoretical ratios of distances in the tetragonal or hexagonal systems of crystals that the readings on the inverted slide of the slide rule had for the cubic system. The experimental data are plotted to the same logarithmic scale on the edge of a piece of paper, and this plot corresponds to the pencil-mark plot on the lower scale of the body of the slide rule. Such charts were made and published for the simple, body-centered, and face-centered tetragonal lattices, and for the simple-triangular, triangular close-packed, and rhombohedral lattices. Although the diffraction pattern was plotted as log *d*, the scale of abscissas was shown in terms of *d* itself, just as on a slide rule, in order to facilitate the work of plotting the pattern. A specimen chart is reproduced in Fig. 46. Fig. 47 illustrates the use of a chart of this

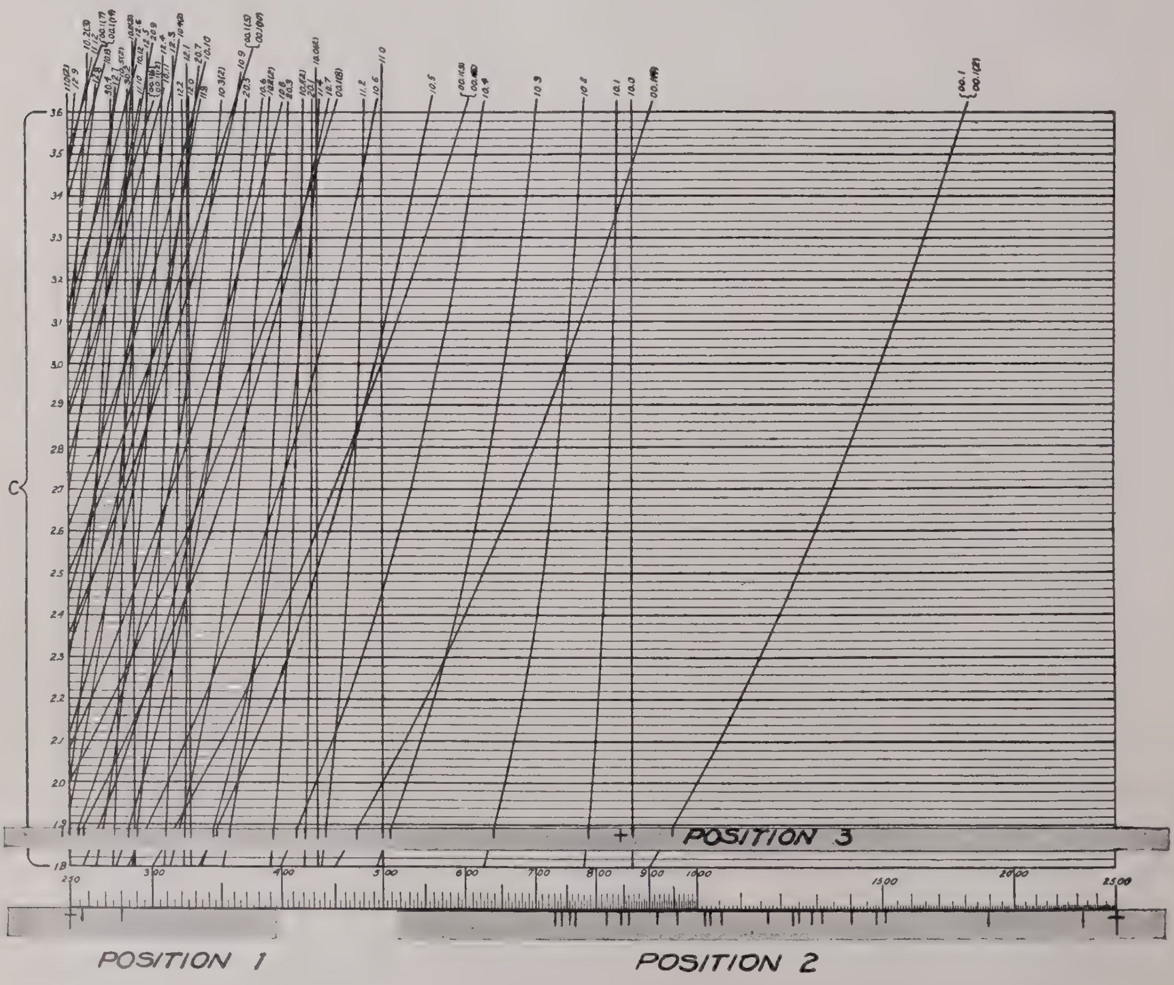

Fig. 47. Interpretation of the Diffraction Pattern of Cd by Means of Semi-log Chart

sort in the interpretation of experimental data on cadmium obtained by Hull(55) (56).

This method of interpretation is also applicable to diffraction patterns of crystals belonging to the orthorhombic system, but no such charts have been made because of the immense amount of labor involved. A series of charts would be needed, each chart showing the dependence of the interplanar distance, d, of equation (22) upon one of the axial ratios, C, while the other axial ratio, A, is kept constant. The whole series of charts would have to cover a range of successive values of A. The ranges from $A=0.90$ to $A=1.10$ and $A=1.50$ to $A=1.90$ are probably the most important. If the charts were limited to values of C lying between $C=0.50$ and $C=1.80$ each chart would require an average of 700 calculations from equation (22). The ranges for A given above would require sixty such charts for the simple orthorhombic lattice alone. The method is even less applicable to diffraction patterns of monoclinic and triclinic crystals. Of course, if the axial ratios and angles are known for some given substance from ordinary crystallographic measurements, the theoretical interplanar distances may be calculated at once, plotted on the inverted side of a slide rule, and compared with the experimental pattern plotted on the bottom scale of the rule. Then a consideration of what lines, if any, are missing may give a clew to the degree of complexity of the inner structure of the unit crystal.

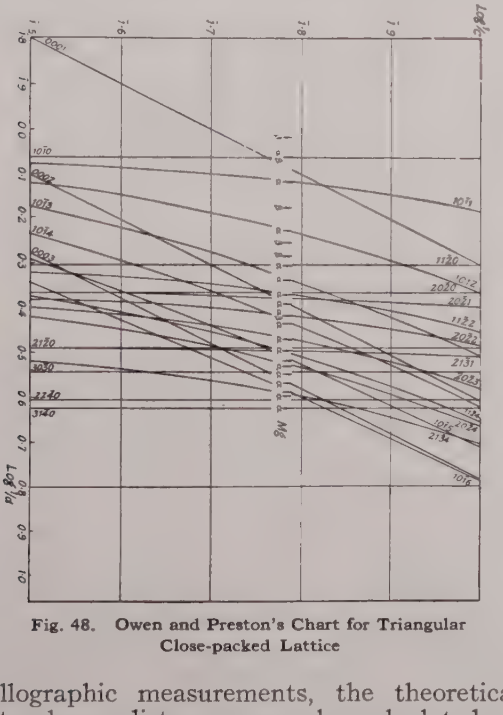

Fig. 48. Owen and Preston's Chart for Triangular Close-packed Lattice

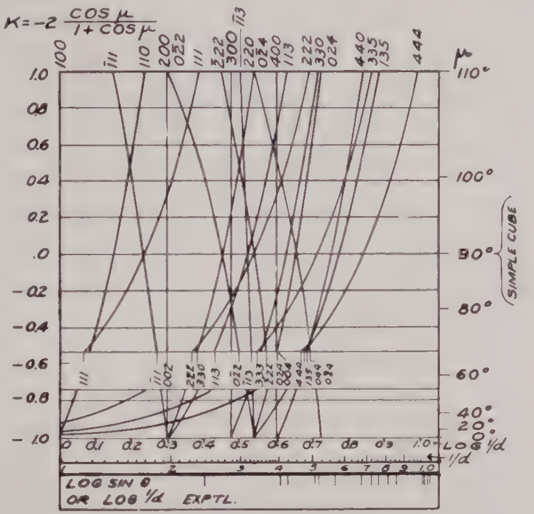

Fig. 49. Interpretation of Diffraction Pattern of Pseudo-graphite by Means of Ewald's Chart

Owen and Preston(57) have published a chart for the interpretation of triangular close-packed lattices in which log $1/d$ and log $1/C$ are the co-ordinates. This has the advantage of including a wide range of axial ratios on a single chart, although at some sacrifice in the accuracy with which the axial ratio may be determined. In using their chart, which is shown in Fig. 48, it should be noted that the scale of abscissas is expressed in terms of the logarithm of $1/d$, not in terms of d directly as in the case of the semi-log chart of Fig. 46. When no filter is used to give a single wavelength of x-rays, the ionization chamber or photographic plate shows two diffraction patterns superimposed, one produced by the "alpha doublet," the other by the "beta line" of the x-ray beam. If the scale of abscissas is taken as log sin θ instead of log $1/d$ it is evident that the angles of diffraction for the beta line can be plotted directly on the same strip of paper as the angles for the alpha doublet. Either of these patterns may then be used independently of the other. Fig. 48 shows some of the beta pattern for Mg crystals plotted along with the alpha pattern.

Ewald(2) has published an incomplete chart of a rhombohedral lattice regarding it as a distorted cube, and using the trigonal axes of equation (29). Several lines are missing, but the chart, shown in Fig. 49, serves well enough to illustrate how, instead of an axial ratio, the angle μ between the axes may be used in the interpretation of rhombohedral structures. Like Owen and Preston, Ewald plots log $1/d$ or log $\sin \theta$ as abscissas. An additional scale has been added in Fig. 49 giving the abscissas in terms of $1/d$ directly. The use of the plot is illustrated by Debye's diffraction pattern of "pseudo-graphite." Ewald's equations differ from equation (29) as they are based on the idea of a "reciprocal lattice." His chart therefore uses

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(55) A. W. Hull and W. P. Davey, *Phys. Rev.* 17, 549 (1921)
(56) A. W. Hull, *Phys. Rev.* *17*, 571 (1921).
(57) E. A. Owen and G. D. Preston, *Proc. Phys. Soc.* (London), *35*, 101, (1923).

$$k = -2 \frac{\cos \mu}{1 + \cos \mu}$$

as ordinates. The corresponding values of the angle μ are given on a separate scale of ordinates.

Owen and Preston⁽⁵⁷⁾ have also proposed a graphical solution of the diffraction patterns of cubic crystals. They write equation (1) in the form

$$n \lambda = 2\, ka \sin \theta$$

where a is the side of the unit cube and k is a constant for any given family of planes for some one value of the wavelength λ. This may be written

$$\frac{n}{a} = \frac{2\,k}{\lambda} \sin \theta$$

showing that for any given wavelength of x-rays the relation between n/a and $\sin \theta$ may be represented graphically by a family of straight lines passing through the origin. Their charts for body-centered and face-centered cubes are shown in Figs. 50 and 51, using the Mo characteristic rays $\lambda_\alpha = 0.710\ A$ and $\lambda_\beta = 0.631\ A$.

Number of Lines Required

No matter what method is used for the interpretation of diffraction patterns, too much emphasis cannot be placed upon the necessity for having a sufficiently large number of lines in the diffraction pattern. It has already been shown that the ratios between the interplanar distances for the first six lines of a simple cubic pattern are the same as for a body-centered cubic pattern. Many other instances will be found from the semi-log charts corresponding to Fig. 46, where the first few lines are often identical for widely different crystal structures. Such diffraction patterns can only be differentiated from each other when lines are present in sufficient number.

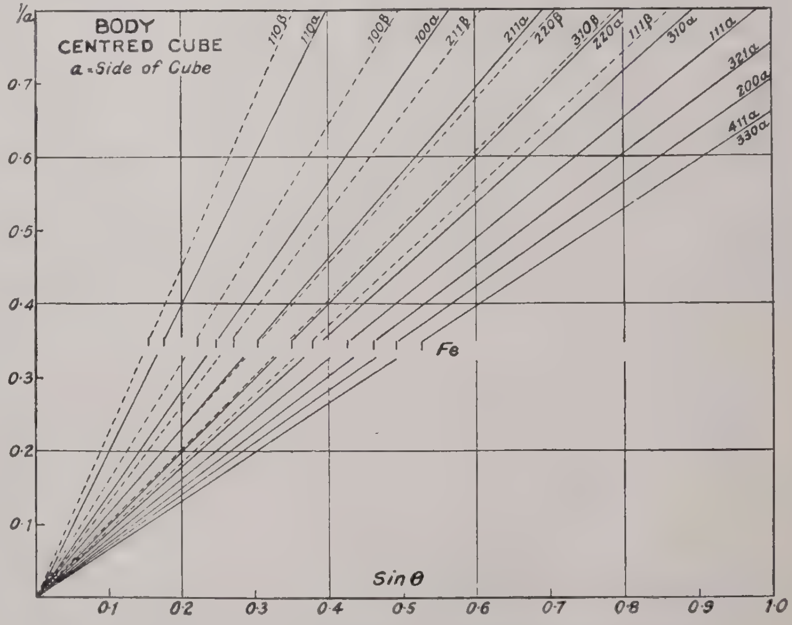

Fig. 50. Owen and Preston's Chart for Body-centered Cubic Lattice

In most cases the diffraction pattern should be investigated through an angle corresponding to an interplanar distance of 0.7 A. In the case of some crystal structures such as the face-centered cubic an angle corresponding to 0.8 A is sufficient. The number of lines in a diffraction pattern of a powder is greater the shorter the wavelength of x-rays employed, for the smallest interplanar distance which will diffract the rays is, from equation (1),

$$d = \tfrac{1}{2}\lambda$$

The longer wavelengths such as are characteristic of Fe and Cu give more accurate determinations of the larger interplanar spacings, and in special cases have considerable real advantage for such purposes. The wavelength for Fe is too long to give enough lines for the satisfactory solution of crystal structures even when the x-rays are bent through an angle $2\,\theta = 180$ deg. The wavelength for Cu requires 180 deg. for an interplanar distance of 0.77 A. Both wavelengths are so long as to require a special window on the x-ray bulb, and this in turn necessitates operating the tube while connected to the pump. The objections to this are obvious to anyone who has ever tried it. The very short wavelengths such as are characteristic of W, λ = 0.2 A, give angles of diffraction which are so small as to interfere seriously with accuracy of measurement, especially on a photographic film. An interplanar distance of 0.7 A bends these rays through an angle 2 θ of about 16 deg. The upper left-hand corner of Fig. 46 shows that, in extreme cases at least, there is a practical limit to the number of lines in a diffraction pattern which are useful in solving a crystal structure by the ordinary graphical methods, so that we are led to the conclusion that the short wavelengths from W, Pt, etc. are ordinarily of little value in crystal analysis by the powder method. The wavelengths which are characteristic of Mo, Rh, or Ag are sufficiently penetrating to permit the use of an all-glass x-ray bulb which has been pumped out once for all and sealed off from the pump. An interplanar distance of 0.7 A corresponds to an angle 2 θ of about 60 deg. for Mo rays. This means that if a photographic film is bent on an arc of 8 in. radius, interplanar distances of 2.0 A can be determined to ¼ per cent, and distances of 1.6 A or less can be determined easily to 1/10 per cent. Greater accuracy is rarely useful because the traces of impurities ordinarily found in even "chemically pure" materials seem to make variations from sample to sample of the order of 1/10 per cent in the parameters of crystals from different sources. For instance, the side of the unit cube of 99.9 per cent Ag is 4.058 ± 0.004 A, while the value for 99.999 per cent Ag is 4.079 ± 0.004 A.(58) Considerations of this sort, coupled with the fact that the x-ray tube itself imposes certain limitations upon the choice of a target material and therefore indirectly upon the choice of a filtering material, have led users of the powder method in this country to the almost exclusive use of Mo alpha rays, a radius of curvature of the photographic film of 8 in., and an exposure time sufficient to show a diffraction pattern throughout an arc of at least 60 deg.

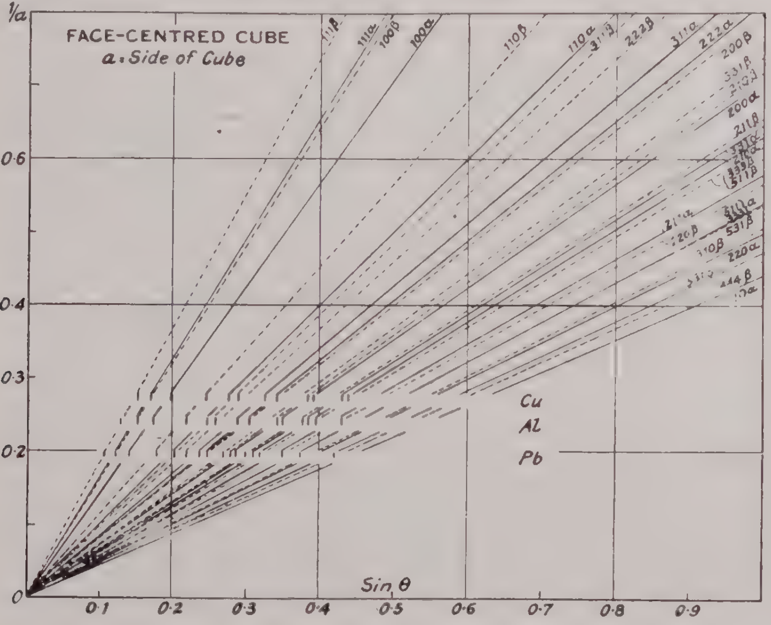

Fig. 51. Owen and Preston's Chart for Face-centered Cubic Lattice

(*To be continued*)

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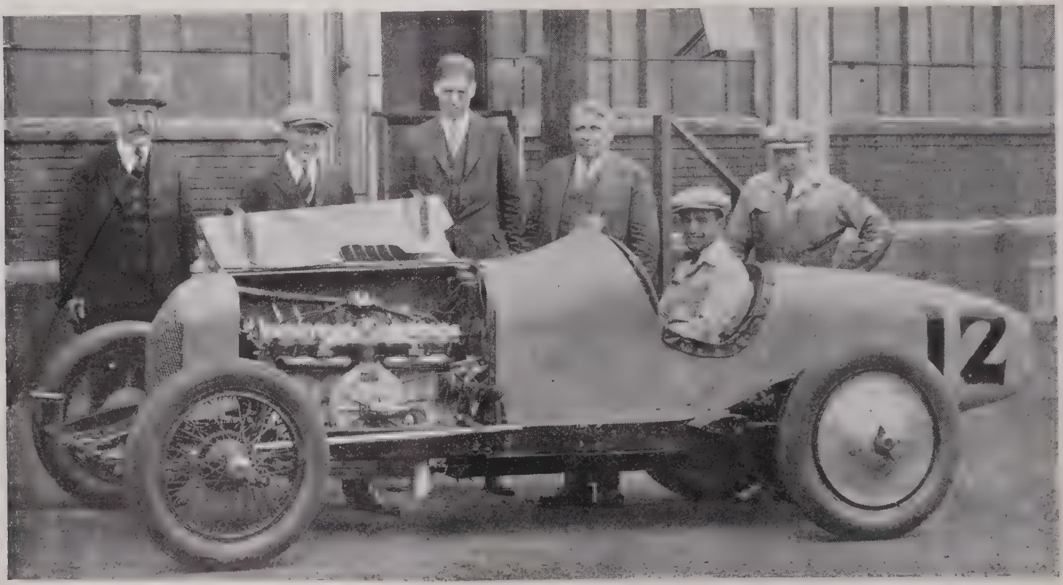
(58) W. P. Davey, *Trans. Am. Soc. Steel Treating*, 6, 375 1924); *Phys. Rev.*, 25, 375 (1925).

The Internal Combustion Engine Supercharger

Two recent automobile racing events were won by Peter de Paolo driving a special Duesenberg straight-eight racing car, equipped with a General Electric type supercharger connected to the carburetor. It would seem at first thought that the construction of racing automobiles could have little to do with the progress of the electrical industry. There are problems, however, in connection with high-speed gasoline engines which have caused their designers to call for outside assistance.



One of these problems is the feeding to the cylinders of the large quantity of oxygen and fuel required at excessive speeds. Formerly, the difference in pressure between the atmosphere and the intake manifold was relied upon to suck air and gas through the carburetor and into the engine. It was found, however, that on certain high speed machines this natural pressure difference was not sufficient when the engine was delivering its full power. This failure was particularly marked in airplane engines at high altitudes. At 20,000 feet the pressure difference was so much reduced that the engine could obtain fuel for only half of its rated power at sea level. To meet this situation, there was developed a successful supercharger, consisting of an exhaust gas turbine driving a centrifugal air compressor. With this, air at sea-level pressure could be delivered to the carburetor regardless of the altitude.

The success of the supercharger for airplanes was so marked that it has recently been applied to the racing automobile, where the excessive demand for an explosive mixture at racing speeds overtaxes the natural pressure difference available even at sea level. In addition to supplying a satisfactory manifold pressure, the supercharger brings about a more even mixture of gasoline and air, and makes possible a more thorough scavenging of burnt gases from the cylinders. The results have been such that some form of supercharging apparatus is now considered a necessity on all racing automobiles.

The supercharger shown in the illustration is driven by gears direct from the crankshaft of the engine, this method having proved more suitable than turbine drive for this class of service. The impeller within the blower casing rotates at speeds up to 30,000 r.p.m. and is capable of maintaining a pressure of 10 pounds per square inch in the manifold.

According to Dr. S. A. Moss, the designer of the supercharger, a similar type of high pressure blower has been profitably extended to Diesel engine installations in sea-going ships, where it is capable of bringing about notable increases in power and speed.

The Charles A. Coffin Foundation Fellowships Awarded in 1925

One of the several purposes of the Charles A. Coffin Foundation, which was established by the General Electric Company to honor its first President, is to make annual awards of fellowships in the fields of electricity, physics, and physical chemistry to graduates of universities, colleges, and technical schools in the United States who have shown, by the character of their work, that they could with advantage undertake or continue research work in educational institutions either in this country or abroad, but who without financial assistance would be unable to devote themselves to this work.

The present fellowships apply to the college year 1925–1926 and constitute the third annual group that has been awarded. The students to receive this assistance from the Foundation were selected on this occasion by a committee consisting of Dr. Farley Osgood, Chairman, representing the American Institute of Electrical Engineers, Dr. John C. Merriam, representing the National Academy of Sciences, and Dr. A. A. Potter, representing the Society for the Promotion of Engineering Education, with W. W. Trench, secretary of the Foundation as secretary.

Fellowships were awarded to:

Norman C. Beese, to engage in research work at the University of Michigan on vacuum spark spectra of metallic elements, particularly in the extreme ultra violet. Mr. Beese studied for two years at the University of Toledo, and then entered the University of Kentucky, from which he was graduated with the degree of B.S. in 1924, and which conferred the M.S. degree on him the following year. He is at present studying for Ph.D. degree at the University of Michigan. During his work at the University of Kentucky he was laboratory assistant in the Department of Physics for more than two years. His home is in Toledo, Ohio.

Reginald H. Benedict, of Medford, Wisconsin, a senior in the electrical engineering course at the University of Wisconsin. Mr. Benedict will take up research work on electrical insulation at the University of Wisconsin, where he has been following a course in that subject.

Paul L. Betz, of Baltimore, Md., who is now a graduate student at Johns Hopkins University, from which institution he received the degree of B.S. in electrical engineering in 1924. During the past year he has been a graduate student there in electrical engineering, physics, and mathematics. He plans to undertake research work at Johns Hopkins in dielectric losses in composite insulation.

Lester H. Colbert, of Columbus, Ohio, who is a senior at the Ohio State University in the electrical engineering course. He expects to take up research work at that university on the magnetic properties of iron and its alloys, and x-ray analysis of alloy steels.

King E. Gould, of Stillwater, Oklahoma, who was graduated with the degree of B.S. in electrical engineering from Oklahoma Agricultural and Mechanical College in 1924, and who during the succeeding year has been studying at Massachusetts Institute of Technology for a master's degree, and doing research work on instability effects in transformers. He plans to devote the coming year to research work on the magnetic behavior of iron at that Institute.

Harold P. Knauss, of Allentown, Pa., now a graduate student at New York University, where, while doing post graduate work, he is serving as an instructor in physics. Mr. Knauss was graduated from Muhlenberg College in 1922 with the degree of B.S. He then entered New York University and received the M.S. degree last year. He will enter the University of Leyden, Holland. The particular field of his work will be determined by facilities offered by the university laboratory and the researches being conducted there.

Harold N. Rowe, who was graduated from Union College in 1923 with the degree B.S. in electrical engineering, and who has since been following a post graduate course and acting as instructor in mathematics there. Mr. Rowe will enter the University of Chicago and take up research work on positive particle and electron emission phenomena.

Donald F. Weekes, of Amherst, Mass., who was graduated from Middlebury College in 1924 with the degree of B.S., and receives an M.A. degree from Amherst this year. During the year 1924–25 he has been graduate assistant, Department of Physics, in the latter institution. He plans to do research work at Amherst on the correlation of magnetic and physical properties of matter.

Fellowships were renewed to:

Ralph D. Bennett, of Williamson, N. Y., B.S. in electrical engineering, 1921, and M.S. in the same branch of engineering, 1923, Union College, who has been working on a direct test of the quantum theory at the University of Chicago during the past year as a Charles A. Coffin Fellow. Mr. Bennett will continue at Chicago through the summer quarter, working on a test of the quantum theory of x-ray scattering. In the fall he will return to Union College as assistant professor of physics.

George Howard Carragan, of Saratoga Springs, N. Y., M.E., Rensselaer Polytechnic Institute, 1918, who has been studying at the Ryerson Laboratory of Chicago University as a Fellow of this Foundation, doing research work on determining the Zeeman effect of the lines of fluorine and who expects to receive his doctor's degree this year. He will continue his investigations of this subject at Chicago during the summer quarter and expects to accept an assistant professorship in physics at Rensselaer Polytechnic Institute in the fall.

Elliott W. Cheney, of Orange, Mass. Mr. Cheney received an A.B. degree from Dartmouth College in 1920, and a M.A. degree from Brown in 1924, acting as instructor at the latter institution while taking his post graduate work. He was accorded a Charles A. Coffin Foundation Fellowship last year, and took up research work on the electron theory at Princeton. He plans to do research work at Princeton in determining the effect of temperature on the index of refraction of gases.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alternators

Self-Synchronizing Alternator.
Engr., May 8, 1925; v. 139, pp. 526-527.
(Illustrates and describes an alternator, designed by L. J. Hunt, which is claimed to give satisfactory operation in parallel under adverse conditions, even with poorly-operating gas engine drive.)

Arc Welding

Arc Welded Steel Building. A. G. Bissel.
Weld. Engr., May, 1925; v. 10, pp. 17-20.

Belts and Belting

Importance of Belt Thickness in Computations. W. F. Schaphorst.
Power Pl. Engng., May 1, 1925; v. 29, p. 483.
(Practical directions for calculation of speeds of belt-driven pulleys.)

Brushes, Electric

Brushes for Electric Motors and Generators. W. E. Stine.
Am. Soc. Nav. Engrs. Jour., May, 1925; v. 37, pp. 312-331.

Chimneys

Stream-Line Stack.
Power, May 19, 1925; v. 61, pp. 788-792.
(On the principles of the Prat or convergent-divergent smoke-stack, as used in Europe.)

Circuit Breakers—Testing

High-Voltage Circuit Breaker Tests. P. Sporn and H. P. St. Clair.
Elec. Wld., May 9, 1925; v. 85, pp. 970-973.
(An account of 132-kv. tests made at the Sunnyside substation of the Ohio Power Co., at Canton, O.)

Coal Storage

Factors Governing the Storage of Coal.
Power Pl. Engng., May 15, 1925; v. 29, pp. 523-525.

Electric Cables

Study of High-Tension Cable Joints.
Elec. Wld., May 23, 1925; v. 85, pp. 1070-1072.
(A summary of papers and discussion presented before the A. I. E. E. regional convention at Swampscott, Mass., on May 8, 1925.)

Oil-Filled Terminals for High Voltage Cables. Eugene D. Eby.
A.I.E.E. Jour., June, 1925; v. 44, pp. 593-600.
(Presents designs for such cable terminals, and describes the results of experiments on them.)

Electric Cables—Testing

Cable-Pulling Tensions. Will G. Kelley.
Elec. Wld., May 16, 1925; v. 85, pp. 1015-1018.
(Presents test results.)

Electric Control Systems

Automatic Control for Substation Apparatus. Walter H. Millan.
A.I.E.E. Jour., June, 1925; v. 44, pp. 588-591.

Automatic Control for Forced-Draft Fans at Wabash River Station. W. C. Plumer.
Power, May 19, 1925; v. 61, pp. 782-783.

Complete Automatic Control of Pumps in Waterworks Plant.
Elec. Wld., May 9, 1925; v. 85, pp. 978-979.

Electric Drive—Ice Manufacture

Electrically Driven Ice Plant. Fred Ophuls.
Refrig. Engng., May, 1925; v. 11, pp. 377-387, 391-392.
(Serial.)

Synchronous Motor Drives in Ice and Refrigerating Plants. Truman Hibbard.
Refrig. Engng., May, 1925; v. 11, pp. 392-398.
(Extracts from a paper read before the Fourth International Congress of Refrigeration, in London.)

Electric Drive—Machine Tools

Machine Tools with Built-in Electrical Equipment. John W. Harper.
Am. Mach., May 14, 1925; v. 62, pp. 780-782.

Electric Drive—Steel Mills

Factors Involved in the Selection of Direct Connected and Geared Main Roll Drives. E. A. Hurme.
Iron & St. Eng., May, 1925; v. 2, pp. 189-222.
(With the discussion forms a lengthy paper on electric drive of steel mill main rolls. Includes numerous charts and curves.)

Electric Heating, Industrial

Industrial Electric Heating Survey. J. L. Faden.
Elec. Wld., May 2, 1925; v. 85, pp. 919-923.
(Results of a survey conducted by the Edison Electric Illuminating Company of Boston to determine the market for industrial electric heat.)

Electric Meters

Selection, Use and Care of Recording Electrical Meters. J. Elmer Housley.
Power, May 5, 1925; v. 61, pp. 690-692.

Electric Meters—Testing

Accuracy Tests for Meggers. H. B. Brooks.
Elec. Wld., May 9, 1925; v. 85, pp. 973-976.

Electric Motors, Synchronous

Self-Excited Synchronous Motors. J. K. Kostko.
A.I.E.E. Jour., June, 1925; v. 44, pp. 604-612.
(An outline of the general theory.)

Electric Ovens

Annealing Glass with the Electric Lehr. Kenneth M. Henry.
Jour. Elec., May 15, 1925; v. 54, pp. 356-358.

Electric Power

Power Possibilities at Muscle Shoals, Alabama. Samuel S. Wyer.
A.I.E.E. Jour., June, 1925; v. 44, pp. 571-578.
(A condensed statement of the facts regarding the fundamental features of the scheme, what has been done to date, and what can still be done.)

Electric Transformers

New Two-Phase to Six-Phase Transformer Connection of One Hundred Per Cent Apparatus Economy. A. Boyajian.
A.I.E.E. Jour., June, 1925; v. 44, pp. 591-592.

Electric Transmission

Over-Voltage on Transmission Systems Due to Dropping of Load. E. J. Burnham.
A.I.E.E. Jour., June, 1925; v. 44, pp. 579-587.
(Shows the manner in which voltage will rise under different conditions. Presents methods of calculation.)

Electric Transmission Lines

Calculations for Transmission Lines. R. G. Hornberger.
Elec. Wld., May 9, 1925; v. 85, pp. 965-968.
(A semi-graphic practical method.)

Electric Welding

Experience with Resistance Welding. G. A. Hughes.
Elec. Wld., May 2, 1925; v. 85, pp. 913-918.
(Considers spot, seam and butt welding.)

Flood Lighting

Commercial Possibilities of Color Flood-Lighting. A. M. Frost.
Jour. Elec., May 15, 1925; v. 54, pp. 351-355.
(A description of equipment used on the San Joaquin Light & Power Corp. building, Fresno, Calif.)

Hydroelectric Plants

Operation of Hydroelectric Systems with Auxiliary Steam Plants for Best Economy and Proper Governing. Wm. Monroe White.
Engrs. & Engng., May, 1925; v. 42, pp. 119-125.
(Serial.)

Hydroelectric Plants, Automatic

Automatic Hydroelectric Plant of the San Gorgonio Power Company. P. B. Garrett.
Elec. Jour., June, 1925; v. 22, pp. 286-289.

Nozzles

Steam Nozzles Research.
Engr., May 15, 1925; v. 139, pp. 536-538.
(A summary of the fourth report of the Steam Nozzles Research Committee of the I. M. E.)

Pipe Joints

Welded Pipe Joints for Power Plants. Eustis H. Thompson.
Power, May 5, 1925; v. 61, pp. 680-682.

Power Plants, Electric

Additional Power for the Tri-Cities.
Power Pl. Engng., May 15, 1925; v. 29, pp. 516-522.
(Detailed account of equipment in the new Riverside station of the United Light & Power Co., near Davenport, Iowa.

Protective Apparatus

Design of Electrical Plant, Control Gear and Connections for Protection Against Shock, Fire and Faults. H. W. Clothier.
I. E. E. Jour., May, 1925; v. 63, pp. 425-473.
(Discusses the various means of guarding against risks to life and plant.)

Lightning Protection of Distribution Systems. A. L. Atherton.
Elec. Jour., June, 1925; v. 22, pp. 301-304.

Radio Engineering—Damping

Optimum Damping in the Auditive Reception of Wireless Telegraph Signals. L. B. Turner and F. P. Best.
I. E. E. Jour., May 1925; v. 63, pp. 493-501.
(An account of an experimental investigation.)

Radio Engineering—Measurements and Testing

Radio Frequency Measurements. E. B. Moullin.
Wld. Power, May, 1925; v. 3, pp. 252-257.

Railroads—Electrification

I. C. Pioneers in Electrification.
Elec. Trac., May, 1925; v. 21, pp. 229-233.
(Unusual features of the Illinois Central Railroad electrification in the Chicago terminal area.)

Reactors

Eight Years Experience with Protective Reactors. James Lyman and others.
A.I.E.E. Jour., June, 1925; v. 44, pp. 601-603.
(Gives brief accounts of sixteen accidents on the buses or feeders of three large power stations.)

Relays

Protective Relays for Central Station Systems. O. J. Bliss.
W. Soc. Engrs. Jour., May, 1925; v. 30, pp. 229-234.

Statistics—Electrical Fires

Fire Losses During 1923. Reginald Trautschold.
Elec. Wld., May 2, 1925; v. 85, pp. 923-924.
(Statistical article pertaining to fires caused by electricity.)

Steam Plants

Automatic Heat Balance Control. W. A. Kates.
Elec. Wld., May 16, 1925; v. 85, pp. 1025-1027.

Getting the Most Out of Exhaust Steam. Charles L. Hubbard.
Power, May 5, 1925; v. 61, pp. 685-687.

Steam Turbines

Increase in Thermal Efficiency Due to Resuperheating in Steam Turbines. W. E. Blowney and G. B. Warren.
Mech. Engng., June, 1925; v. 47, pp. 455-461.
(Presents the results of tests. Abridgment of the complete paper.)

Substations, Automatic

Automatic Control for Substation Apparatus.
Power Pl. Engng., May 15, 1925; v. 29, pp. 543-546.
(Abstract of an A. I. E. E. paper by Walter H. Millan.)

Two-Unit Automatic Station with Purchased Power Aids Steam Plants at Mines. L. P. Read.
Coal Age, May 21, 1925; v. 27, pp. 753-756.
(Illustrated description of a Consolidation Coal Co. substation near Frostburg, Md.)

Switches and Switchgear

Disconnecting Switches and Primary Cut-Outs for Overhead Distribution. H. J. Crabbs.
Elec. Jour., June, 1925; v. 22, pp. 305-308.

Trolley Wire

New Catenary Construction on the Canadian National. E. B. Walker.
Rwy. Age, May 2, 1925; v. 78, pp. 1099-1101.
(Illustrated description of trolley wire mounting.)

Water Turbines

Mechanical Problems of Hydraulic-Turbine Design. William Monroe White.
Mech. Engng., June, 1925; v. 47, pp. 469-473.

Wattmeters—Testing

Testing 100,000 Meters Yearly. W. R. Frampton and others.
Elec. Wld., May 23, 1925; v. 85, pp. 1067-1069.
(Layout and methods in the Alhambra shops of the Southern California Edison Co.)

NEW BOOKS

Composition of Technical Papers. Ed. 2. Homer A. Watt and Philip B. McDonald. 429 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Connecting and Testing Direct-current Machines. F. A. Annett and A. C. Roe. 237 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Design of Cranes and Hoists. Ed. 2, rev. Hermann Wilda. 159 pp., 1925, Lond., Scott, Greenwood & Son.

Factory Lay-out, Planning and Progress. W. J. Hiscox. 184 pp., 1924, N. Y., Isaac Pitman & Sons.

Foundations of the Universe. M. Luckiesh. 245 pp., 1925, N. Y., D. Van Nostrand Co.
(Mr. Luckiesh presents, in popular style, some of the fundamentals of physical science. Without recourse to mathematics, he has succeeded in producing a very readable book in which he discusses such topics as matter and motion, atoms and molecules, the nature and velocity of light, the electron and the quantum theories, and the postulates of Einstein. These and related phenomena constitute the "foundations of the universe" as used in the title. Although making no pretense of completeness, and though circumscribed by the omission of mathematics, the work should prove of interest to students of science and others of scientific bent who find profit in the simple presentation of the more complex problems of science.)

Inventory Practice and Material Control. Frederic W. Kilduff. 446 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Lighting Fixtures and Lighting Effects. M. Luckiesh. 330 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Practical Foremanship. Glenn L. Gardiner. 191 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Principles of Machine Design. Robert F. McKay. 408 pp., 1924, N. Y., Longmans, Green & Co.

Railway Electrification. H. F. Trewman. 244 pp., 1924, N. Y., Isaac Pitman & Sons.

Relativity and Common Sense. F. M. Denton. 279 pp., 1924, Cambridge, Eng., University Press.

Steam Turbines; Including a Discussion of Mercury and Gas Turbines. Ed. 5, rev. & enl. James A. Moyer. 515 pp., 1924, N. Y., John Wiley & Sons.

Theoretical and Applied Electrochemistry. Rev. ed. Maurice De Kay Thompson. 551 pp., 1925, N. Y., Macmillan Co.

Transmission Circuits for Telephonic Communication; Methods of Analysis and Design. K. S. Johnson. 326 pp., 1925, N. Y., D. VanNostrand Co.
(In the words of its preface, this work "is intended to cover the general theory and principles which are applicable to the development and design of circuits and lines for association with such telephonic instruments as transmitters, receivers, and vacuum tubes. The detailed characteristics and methods of design for these instruments are not here considered. The text assumes on the part of the reader a familiarity with the elements of alternating current theory and with the operations and notations of the complex-quantity method of representing alternating functions.")

Workshop Gauges and Measuring Applicances. Louis Burn. 154 pp., 1924, N. Y., Isaac Pitman & Sons.

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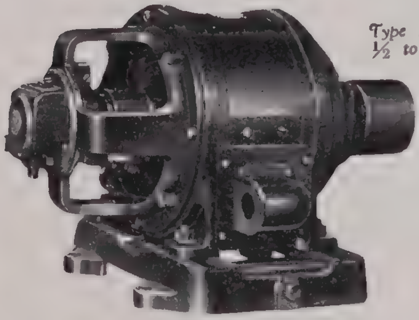

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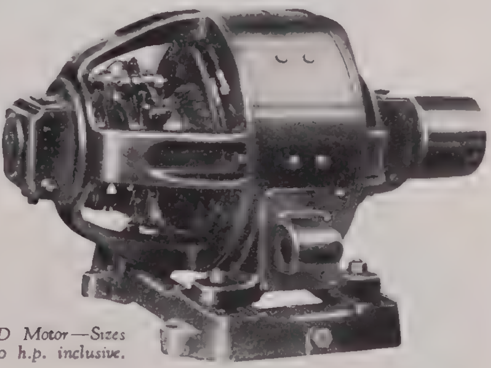

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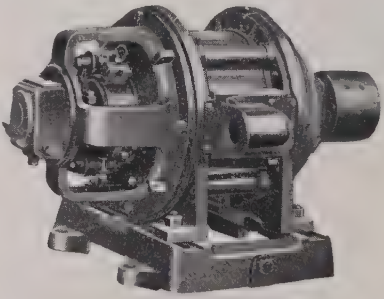

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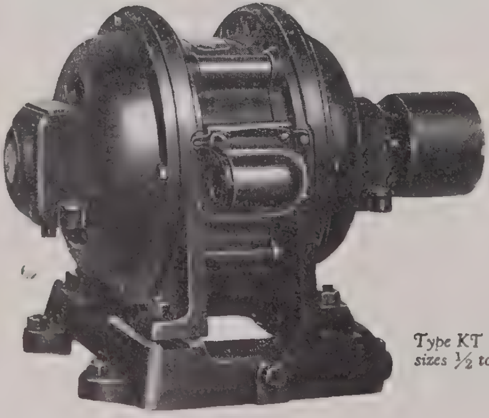

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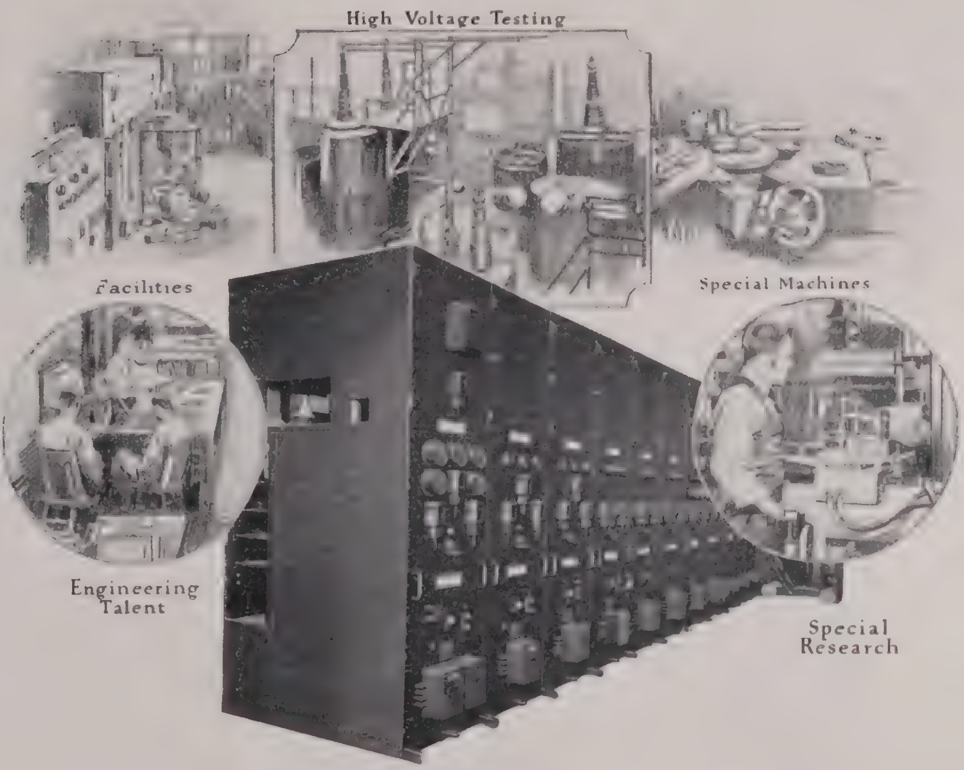

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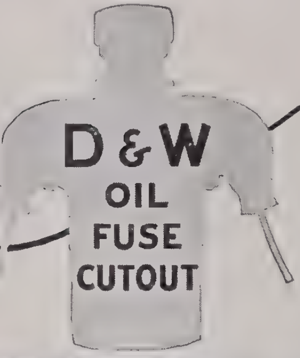
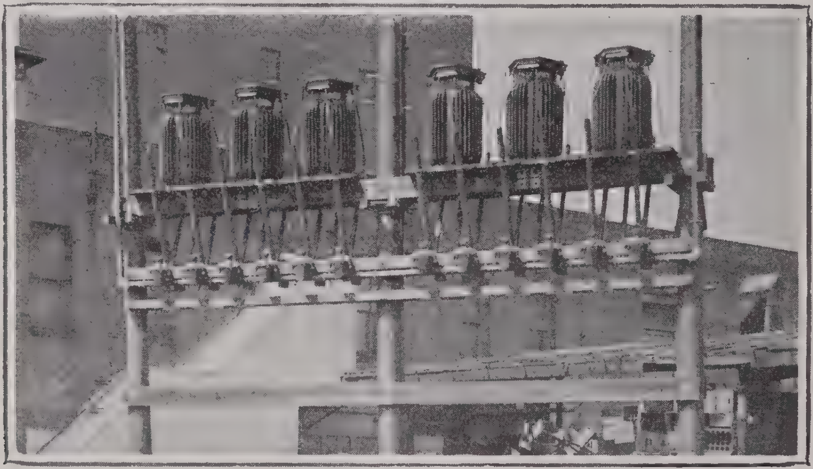


more than a cutout



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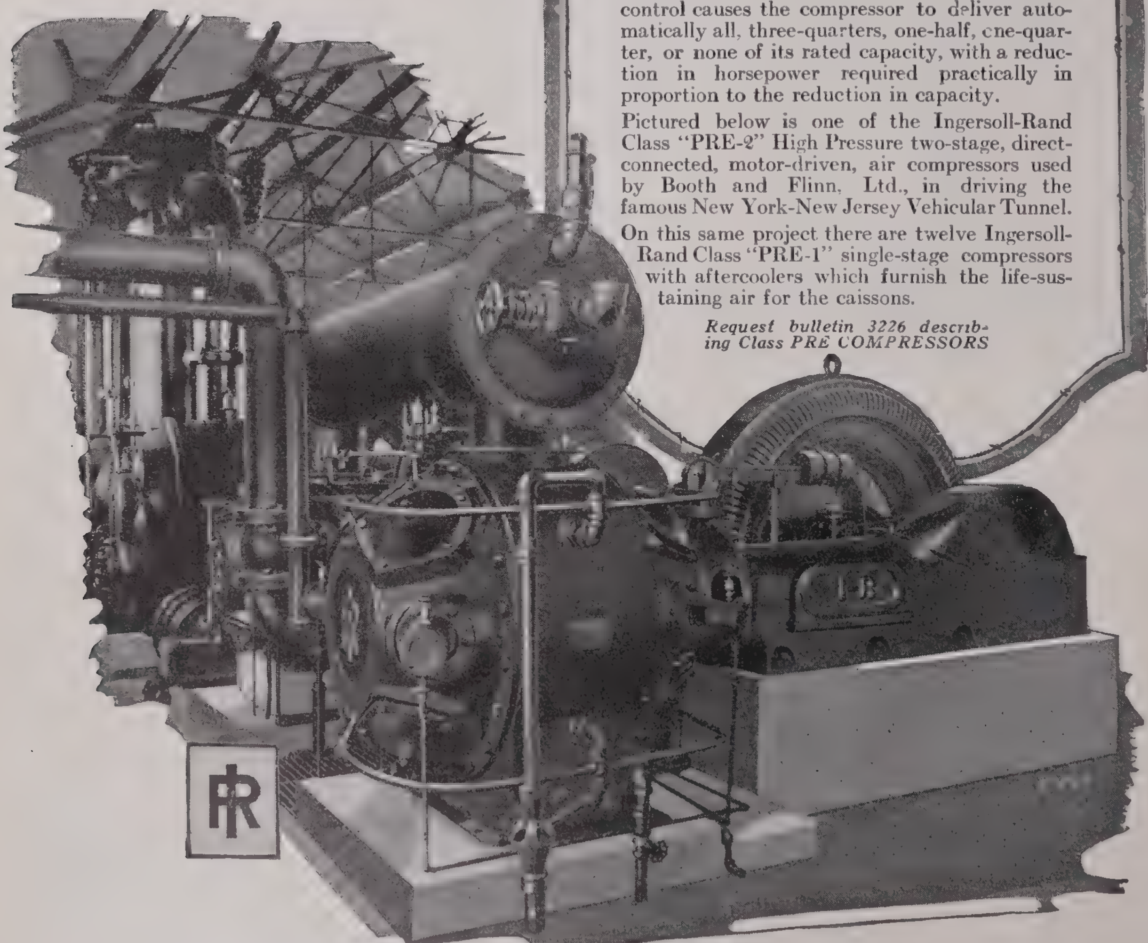

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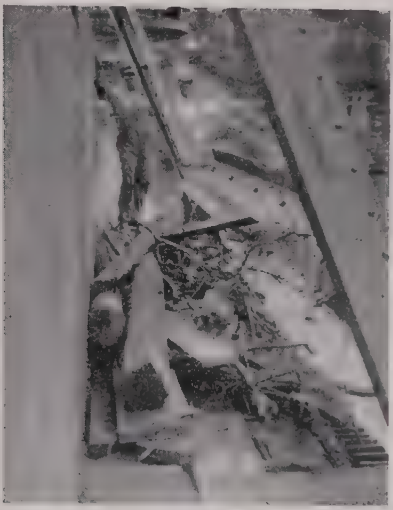

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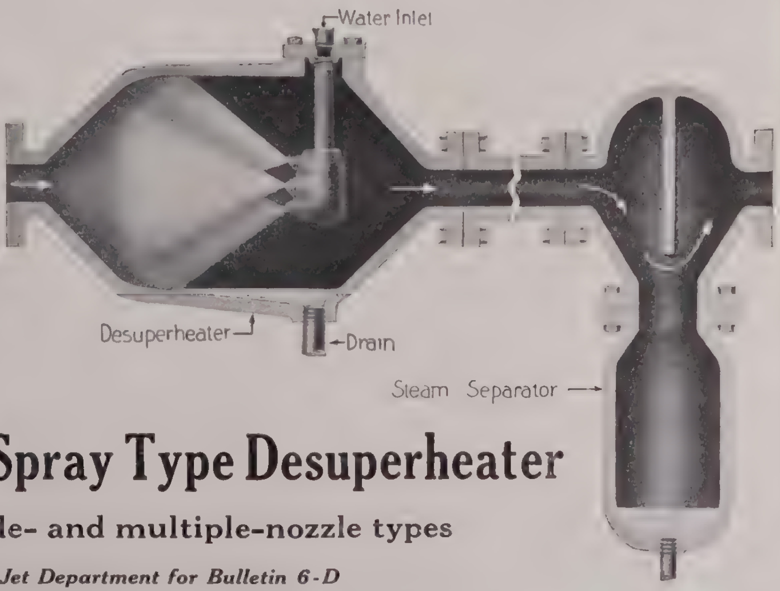

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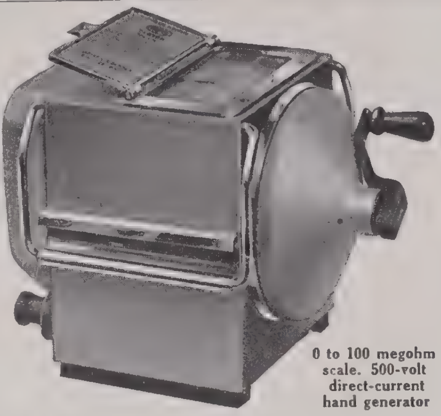

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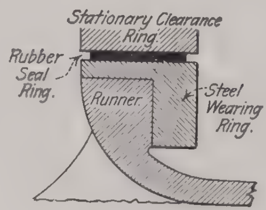

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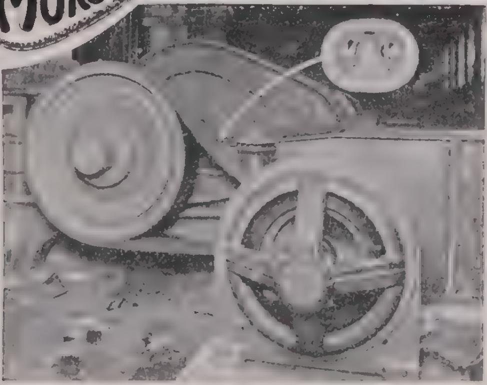

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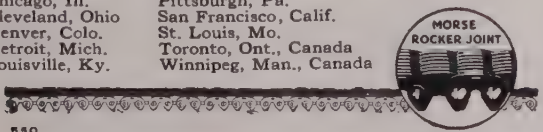

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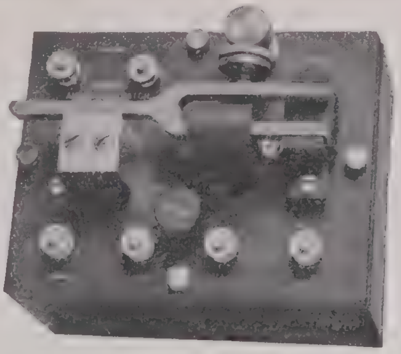

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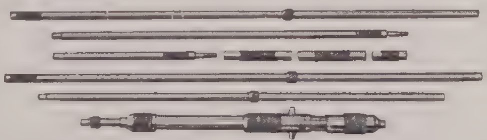

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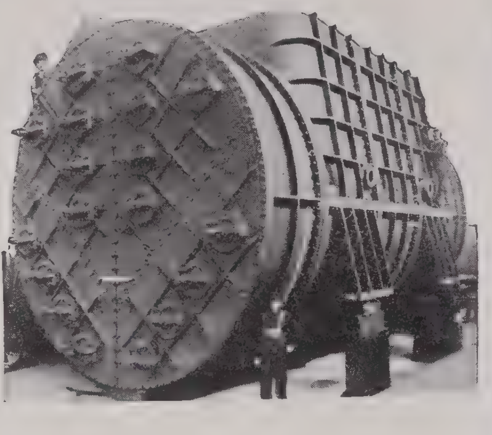

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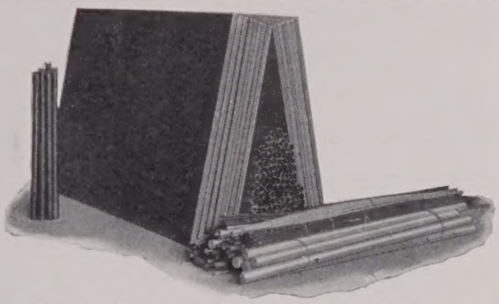

Made in Sheets, Rods, Tubes and Special Shapes

Branches: New York City, Boston, Chicago, Philadelphia, San Francisco, Los Angeles, Detroit, Cleveland Cincinnati

From the red, grey or black, sheets, rods, tubes and all special forms can be sawed, stamped, turned, drilled, threaded and finished in many attractive ways.

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Dams Transmission Lines
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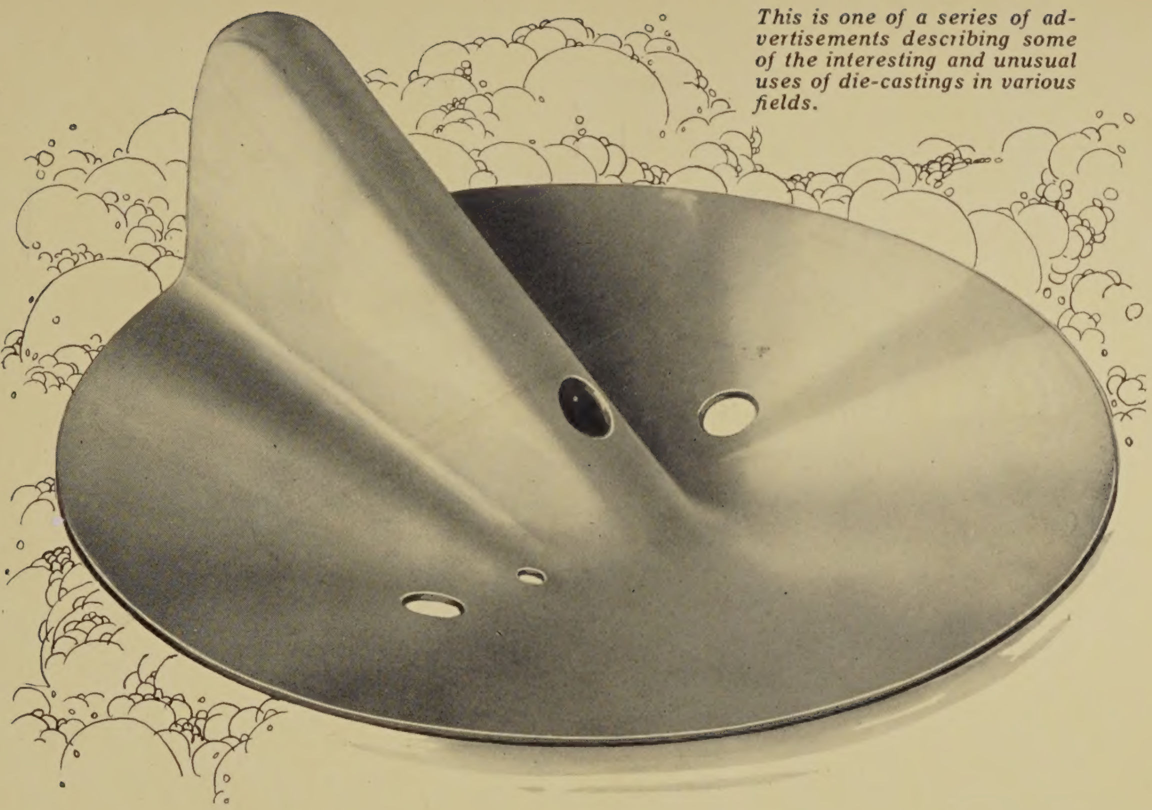
Superstructures as well as Substructures

120 LIBERTY STREET CITY OF NEW YORK

Offices in principal cities throughout the United States and abroad



This is one of a series of advertisements describing some of the interesting and unusual uses of die-castings in various fields.

We don't die-cast the suds

WHILE looking over part after part that we die-cast for electric washing machines, a prospective customer was led to remark: "Why, you seem to die-cast everything except the soap and water."

SUCH is virtually the case. Manufacturers of electric washers make extensive use of die-castings. We die-cast at least two dozen different parts for washing machines including such large pieces as complete wringer frames, stomper arms, and gear boxes.

THE metal disk illustrated is a washing-machine part. It is what makes a certain electric washer wash. Measuring almost a foot and a half across its face and weighing close to four pounds, this disk is one of the largest aluminum die-castings ever manufactured.

MANY parts heretofore considered too big to be die-cast are now being turned out successfully. Try us if you have a large part that you want die-cast.

When you buy die-castings from us, you are assured of the same high quality that has established our Dutch Boy trademark as a mark of excellence on babbitts, solder and paint materials.

NATIONAL LEAD COMPANY

111 Broadway Die-Casting Division New York, N. Y.

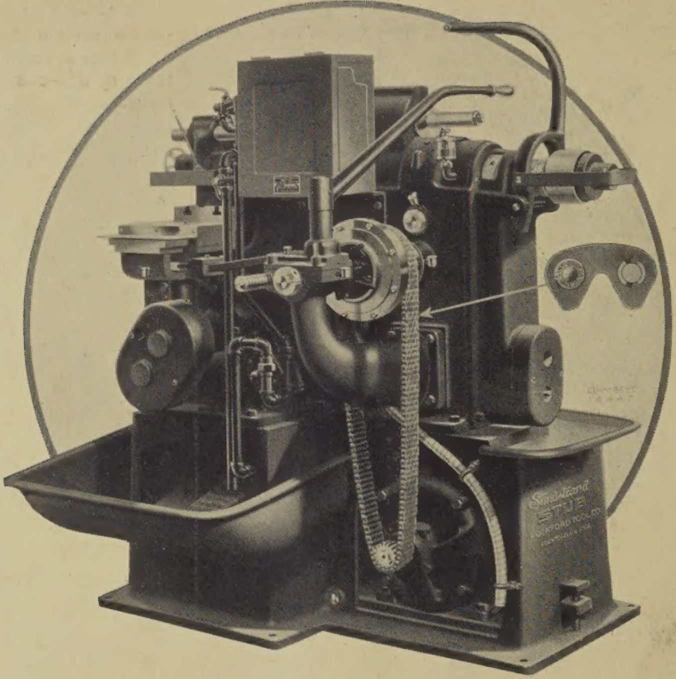
Western Representatives: E. R. McCormick, 2599 Cadillac Ave., Detroit, Mich.; A. H. Bergedick, 667 Bowen Street, Dayton, Ohio. A. A. Gildemeister, 444 Fourth Street, Toledo, Ohio.

ALUMINUM, ZINC, LEAD *and* TIN

DIE-CASTINGS

SILENT

Trade Mark



Why Sundstrand Stub Lathe Uses Link-Belt Silent Chain Drive

BECAUSE it is a modern manufacturing lathe, for machining automotive and other parts manufactured on a production basis, the Sundstrand Stub is equipped with suitable drive—Link-Belt Silent Chain.

With this drive, users are assured of maximum output, since Link-Belt Silent Chain maintains positive velocity ratio between shafts, permitting a uniform production rate, with fewer "rejects" because power is delivered smoothly, without vibration. The durability of the drive, assuring long, trouble-free operation, further contributes to greater output of the machine.

Link-Belt Silent Chain Drive is 98.2% efficient (on actual test), flexible, compact, may be used on short or long centers, and operates equally well in hot, cold, damp, dry, or gritty places.

Keen competition in industry, with its demands for more efficient machines, makes these advantages of vital importance to every machine tool user and builder.

Link-Belt engineers will be glad to show you how you can use this effective drive on *your* machines. Write to nearest office.

Ask for Silent Chain Data Book No. 125.

LINK-BELT COMPANY

Leading manufacturers of Elevating, Conveying and Power Transmission Chains and Machinery

PHILADELPHIA, 2045 Hunting Park Ave.
CHICAGO, 300 West Pershing Road
INDIANAPOLIS, P.O. Box 85
Offices in Principal Cities

LINK-BELT

THIS YEAR LINK-BELT 50 IS FIFTY YEARS OLD

SILENT CHAIN DRIVES